

Measuring Open Bottom Production with Fast MAPS Detector at sPHENIX

Xin Dong

Xiaolong Chen, Guannan Xie

Lawrence Berkeley National Laboratory

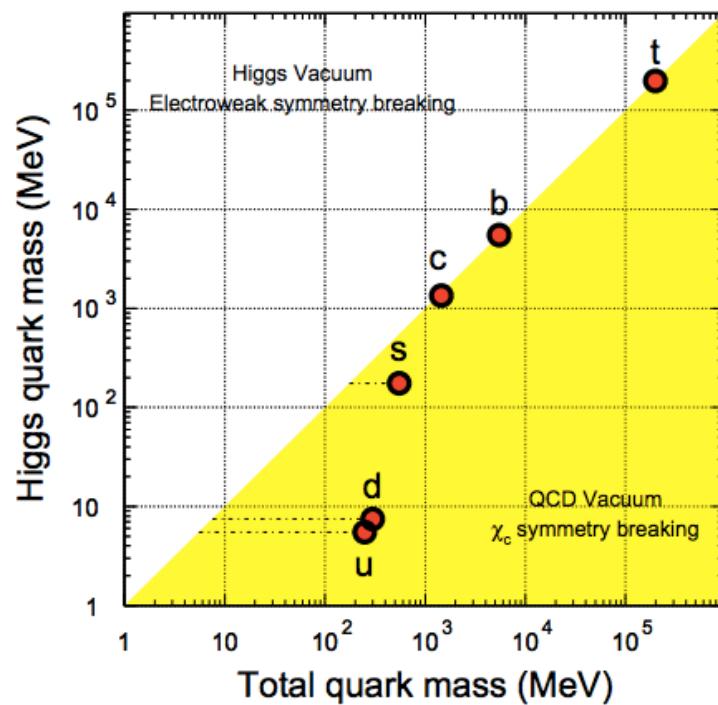
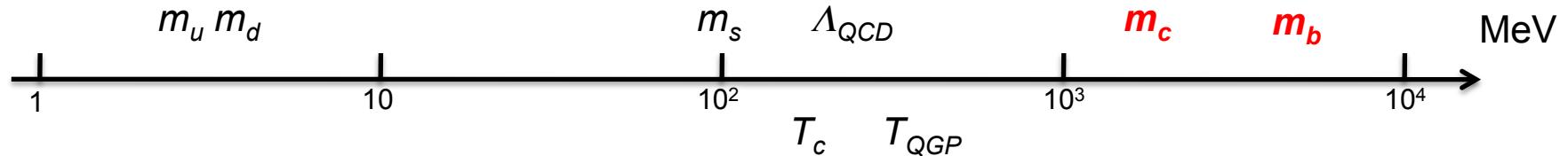


Jan. 5-7, 2017

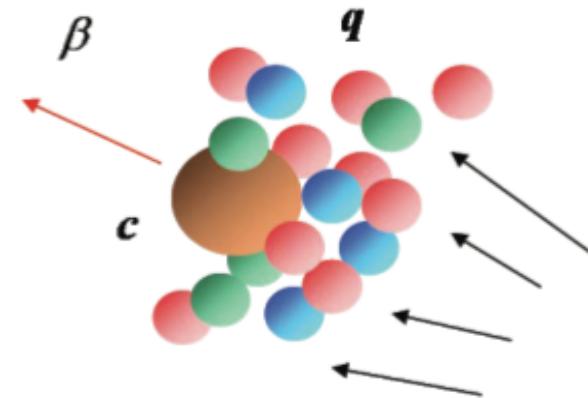
sPHENIX MAPS workfest, Santa Fe

X. Dong

Uniqueness of Heavy Quarks in QCD

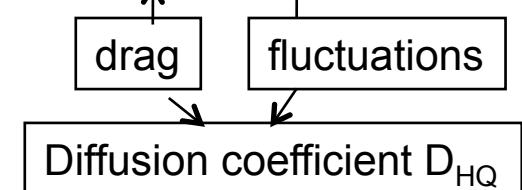


Zhu et al., PLB 647(2007)366



When $M_{HQ} \gg T, M_{HQ} \gg gT$

“Brownian” motion $\frac{dp^i}{dt} = -\eta_D p^i + \xi^i(t)$
 \rightarrow Langevin simu.



Open Bottom Production

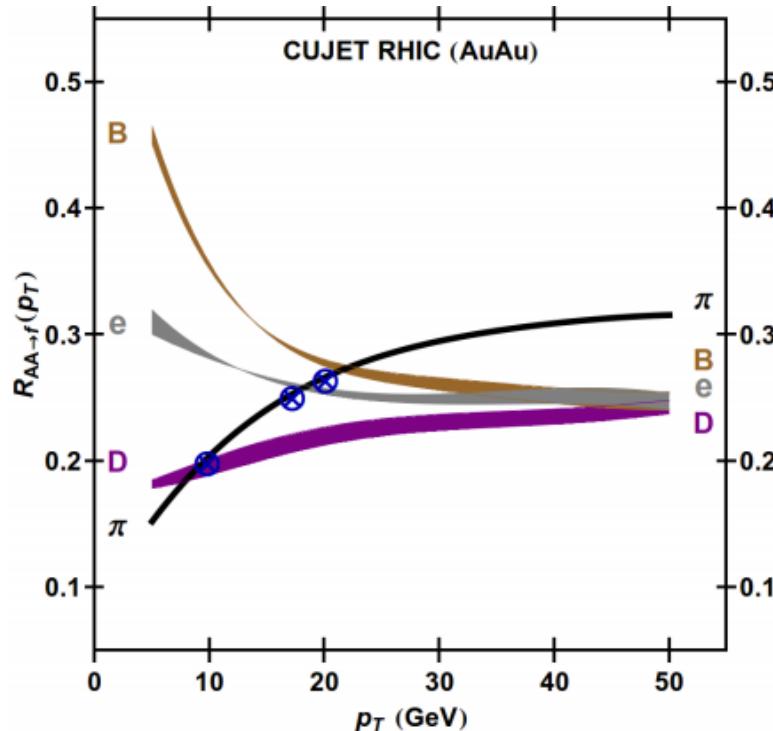
Open bottom production over a wide range of momentum

Flavor dependence of parton energy loss

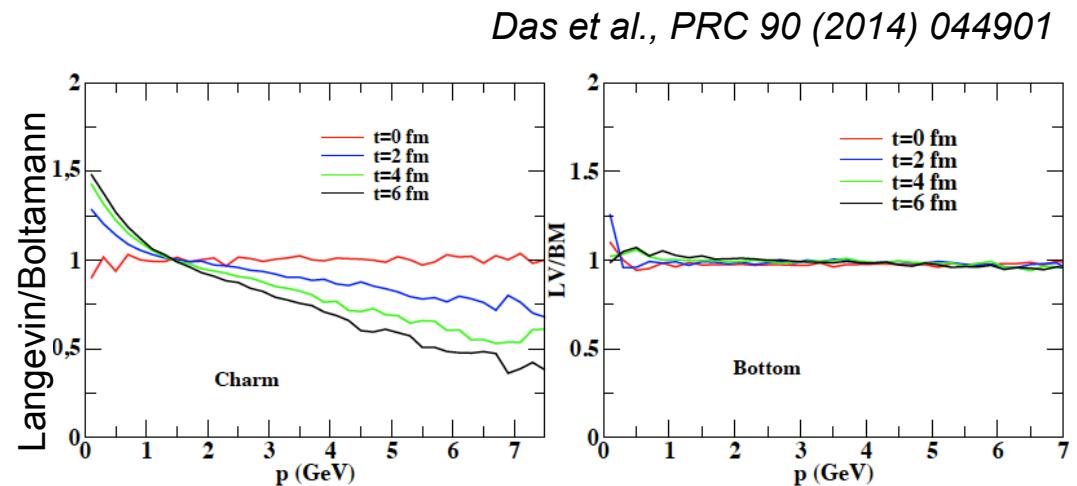
Cleanest probe to quantify medium transport properties – e.g. D_{HQ}

Total bottom yield for precision interpretation of Upsilon suppression

- low p_T coverage is critical



Buzzatti et al., PRL 108 (2012) 022301

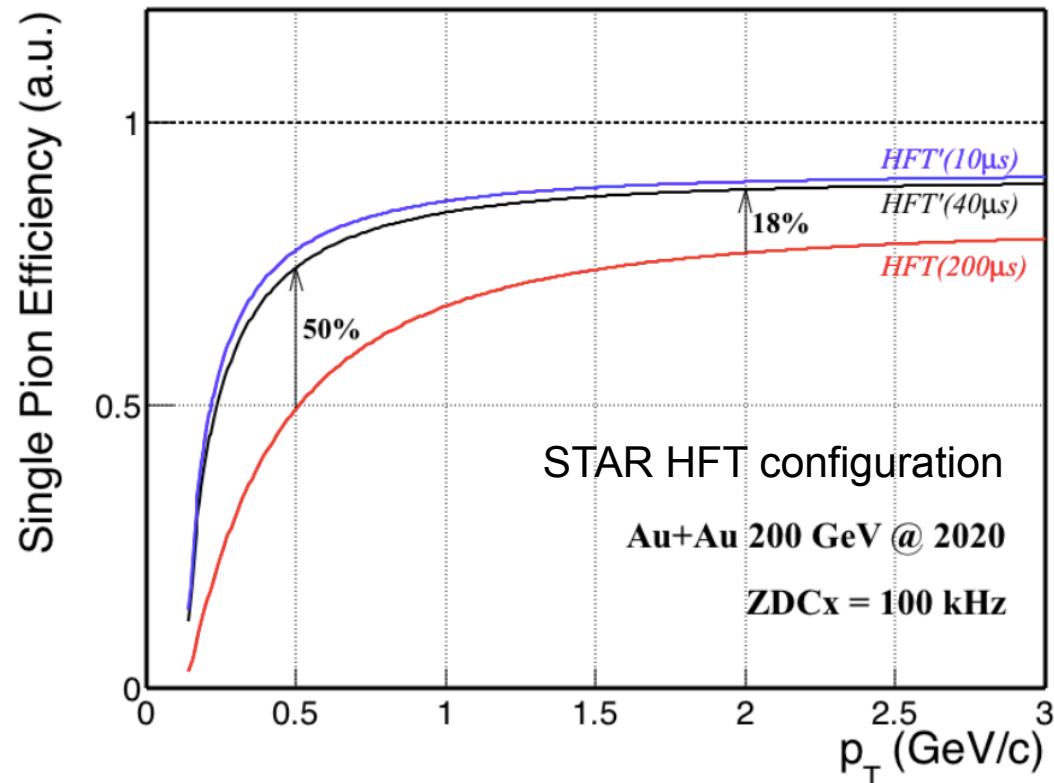


Is charm heavy enough?

Sizable correction to the Langevin approach for charm
- may limit the precision in determining D_{HQ}

Requirements for Precision Open Bottom Production at RHIC

- High luminosity runs and large datasets (triggered and untriggered)
 $B \rightarrow J/\psi$, $B \rightarrow D$, $B \rightarrow e$, $B \rightarrow D\pi$ and b -jet etc.
- Fast silicon detector with ultimate pointing resolution
Next generation MAPS sensors with much shorter integration time $< 20 \mu\text{s}$ (vs. $186 \mu\text{s}$)
 - high efficiency at high RHIC luminosity, particularly at low p_T

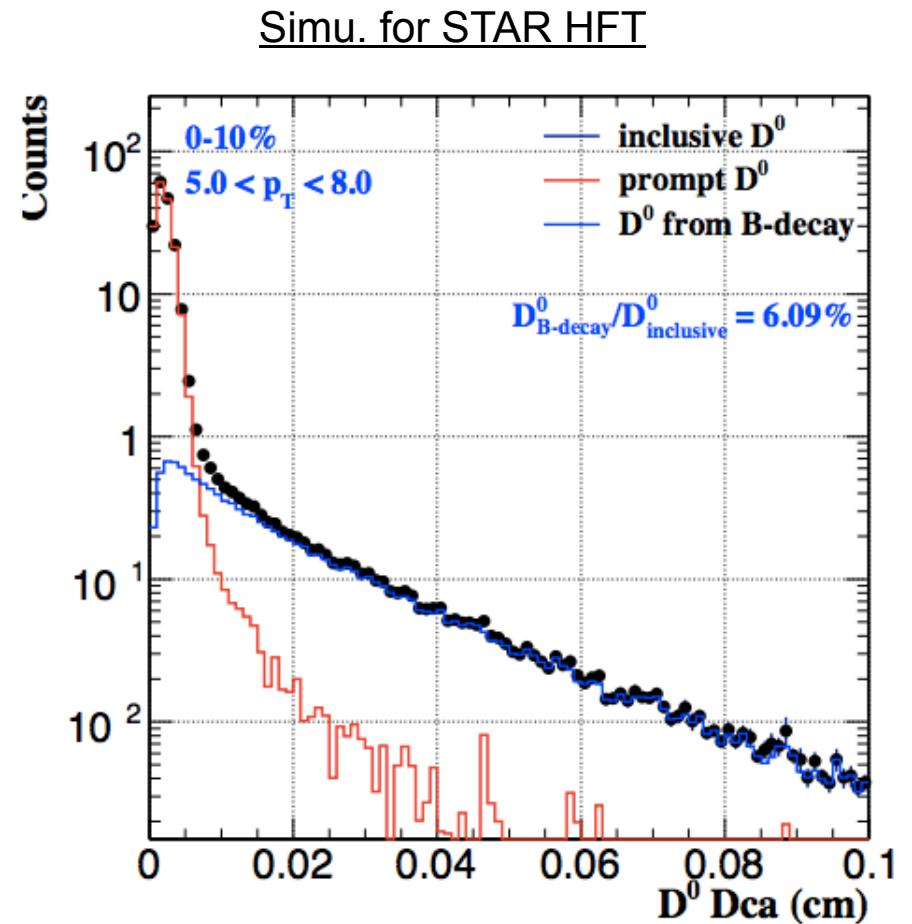


Physics Channels

Hadron	Abundance	$c\tau (\mu\text{m})$
D^0	56%	123
D^+	24%	312
D_s	10%	150
Λ_c	10%	60
B^+	40%	491
B^0	40%	455
B_s	10%	453
Λ_b	10%	435

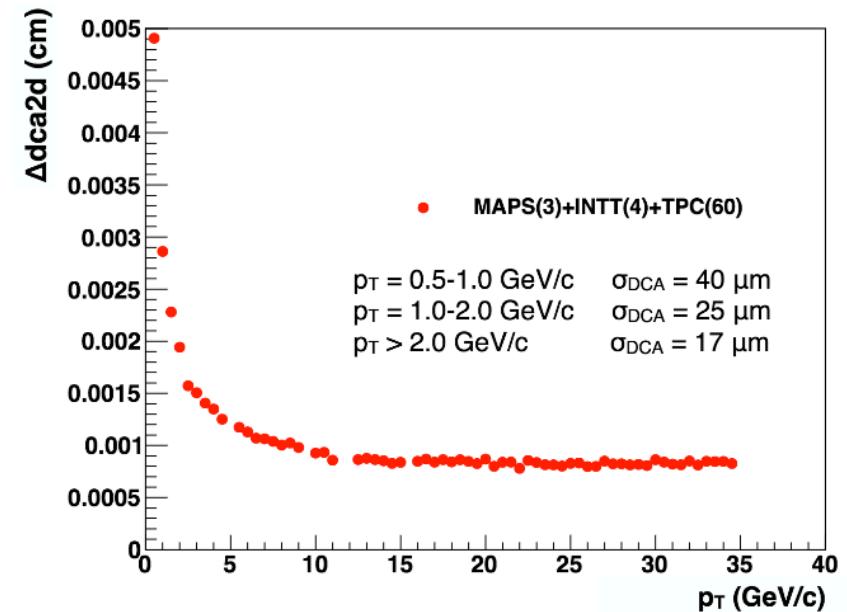
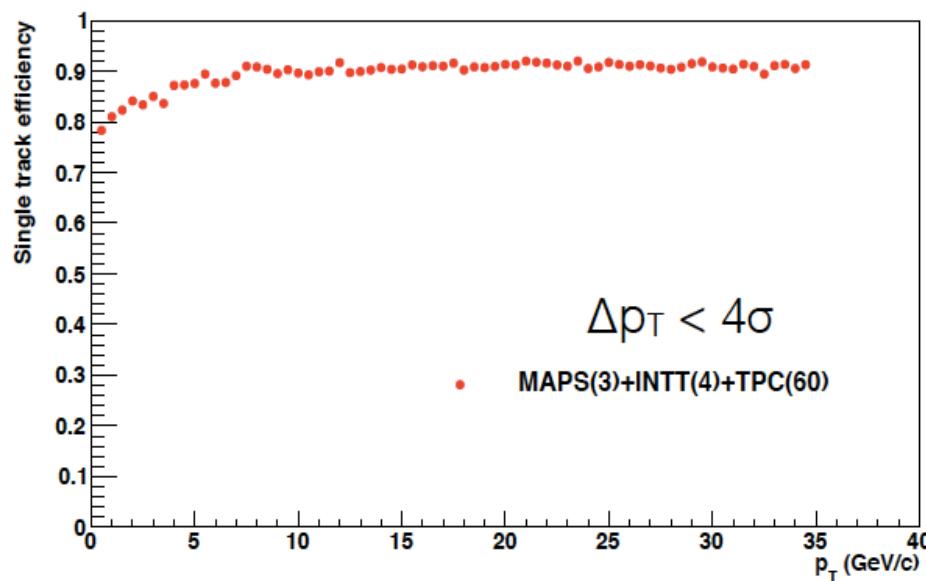
$B \rightarrow J/\psi + X$ 1.2%
 $B \rightarrow \bar{D}^0 + X$ 60%
 $B \rightarrow e + X$ 11%
 $B^+ \rightarrow \bar{D}^0 \pi^+$ 0.5% } Needed for
 $p_T < 10 \text{ GeV}$

b-tagged jet - see Jin's talk



Tracking Performance Input for Quick Estimation

Input distributions coming from sPHENIX full GEANT simulation performance for single track with TPC+INTT+MAPS



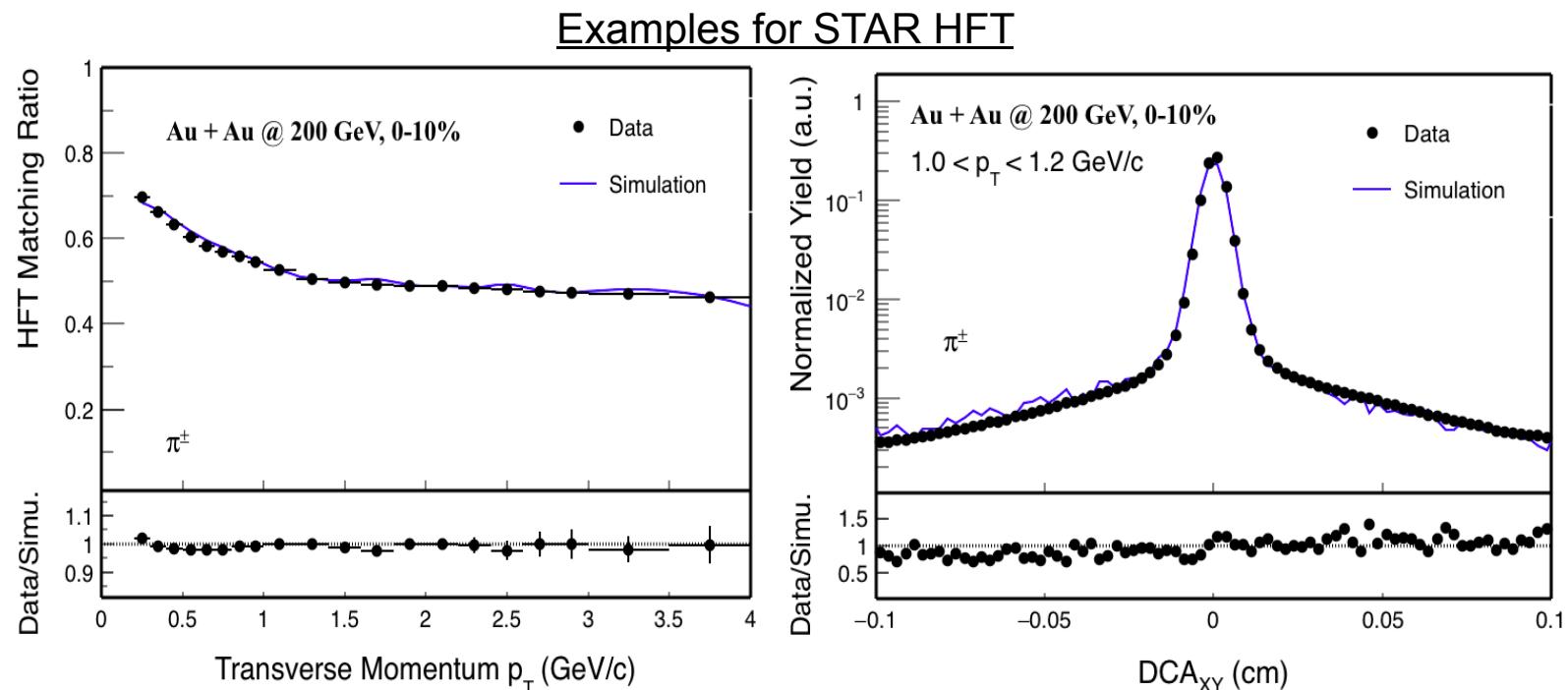
T. Frawley, sPHENIX tracking review, Sept. 2016

A few assumptions - to be verified / fine-tuned with full GEANT simulation

- Low p_T efficiency drop due to fake matches
- Same/comparable resolution in DCA_z dimension, and the correlation between DCA_xy and DCA_z taken from STAR HFT
- The broader DCA structure (due to fake matches) taken from STAR TPC+HFT (conservative)

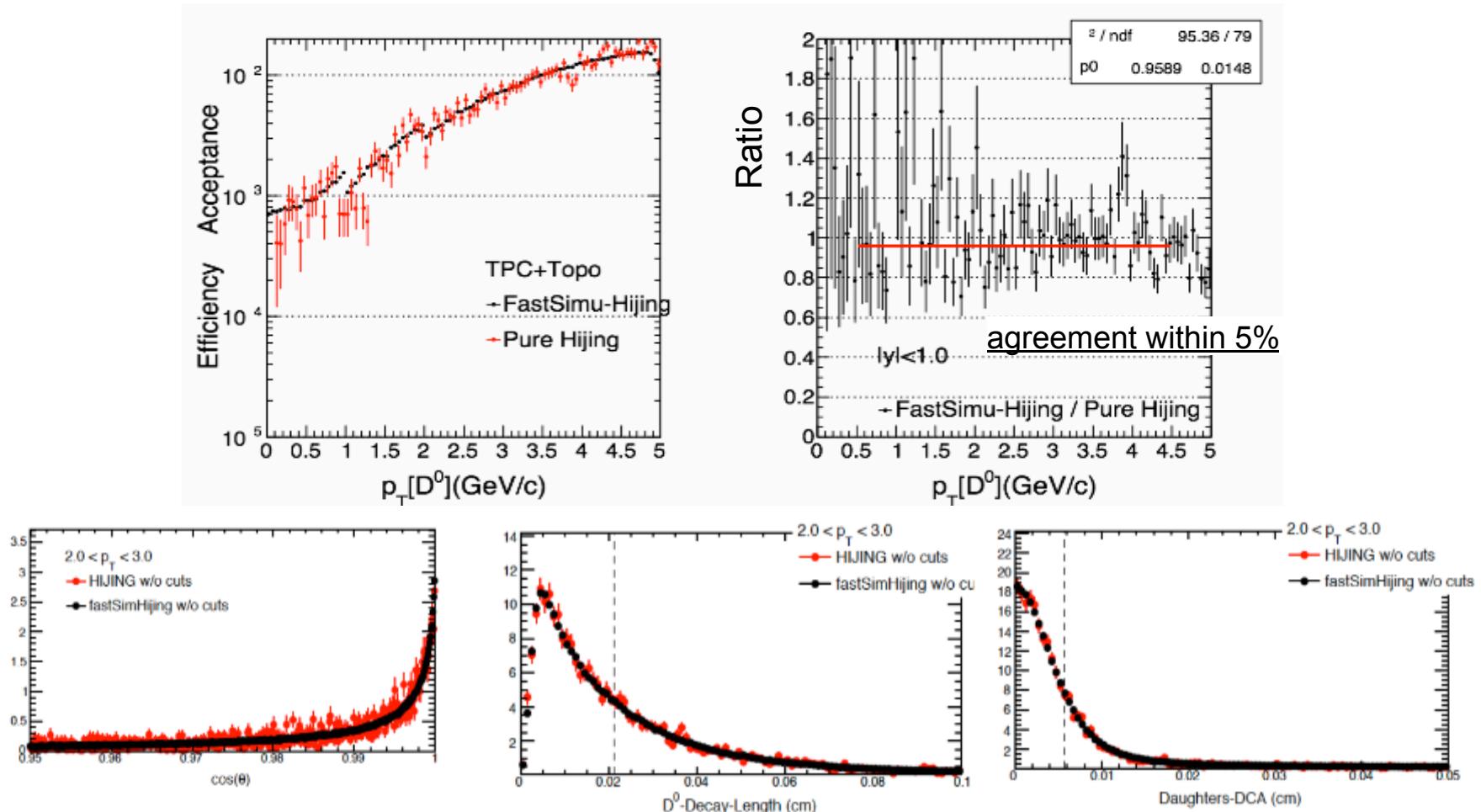
A Bit Detail on the Simulation Estimation

- A fast simulation approach (package used for HFT efficiency calculation too)
 - tracking efficiency characterized by a matching ratio between silicon detectors and the TPC
 - full DCA distributions represent the tracking performance (including good and mismatches) – 2D (DCA_xy vs. DCA_z)
- Goal: to capture full distributions for both signals and combinatorial backgrounds*
- reasonably good for low p_T estimation

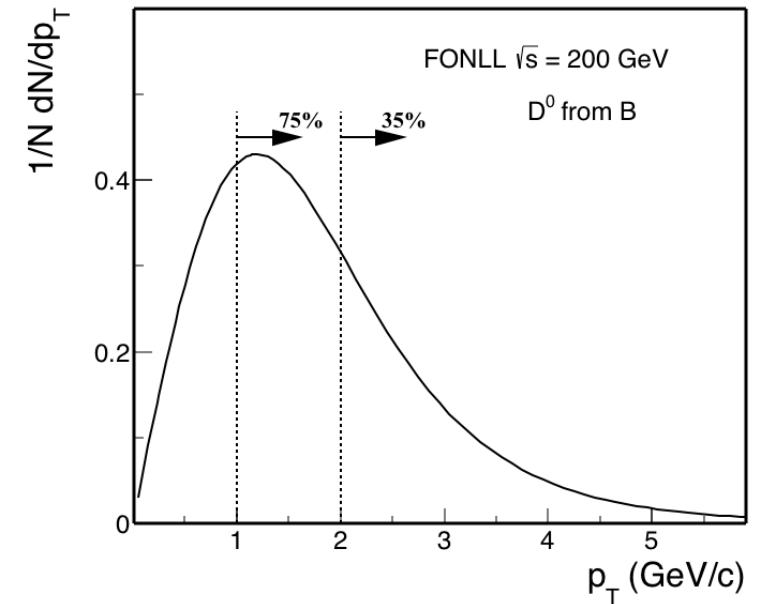
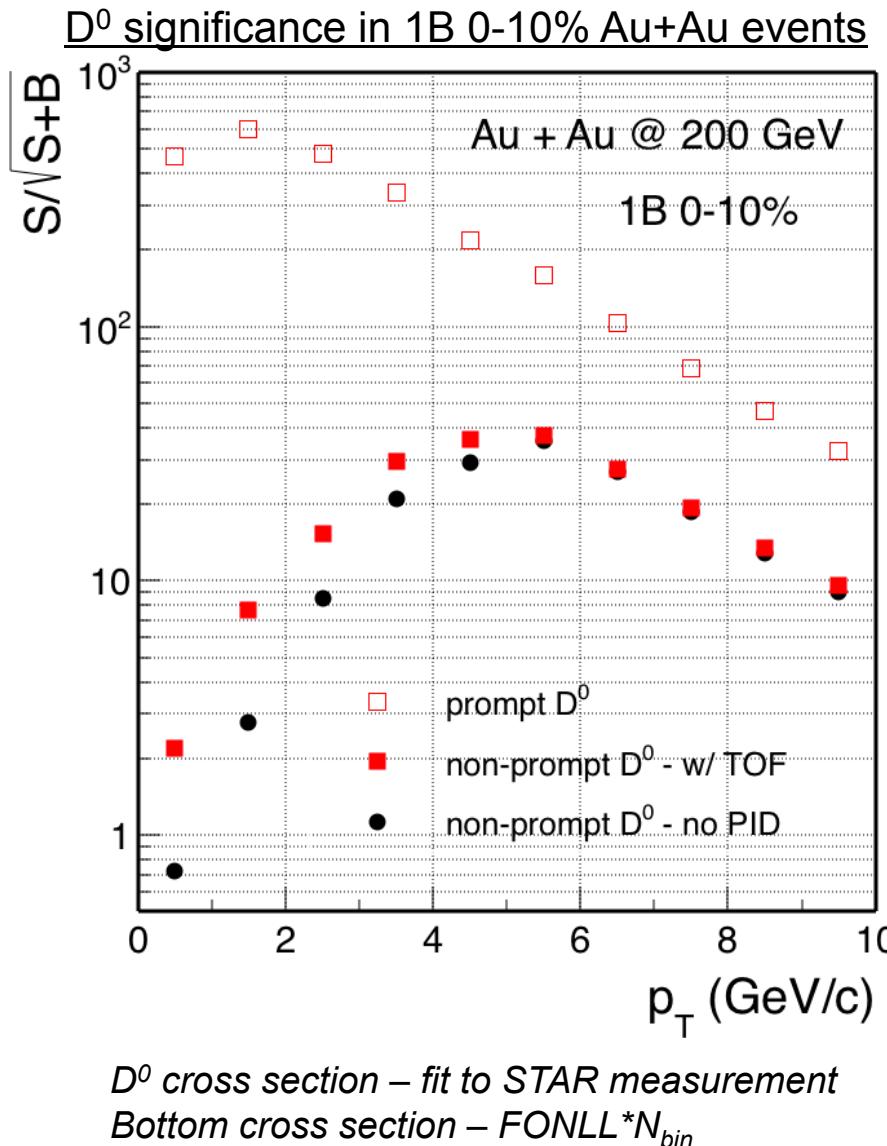


Validation with Full GEANT Simulation

- Hijing+D⁰ sample through GEANT + reconstruction
- Fast simu – inputs taken from Hijing single track performance
- Then compare the efficiencies between fast simu vs. that from Hijing+GEANT directly



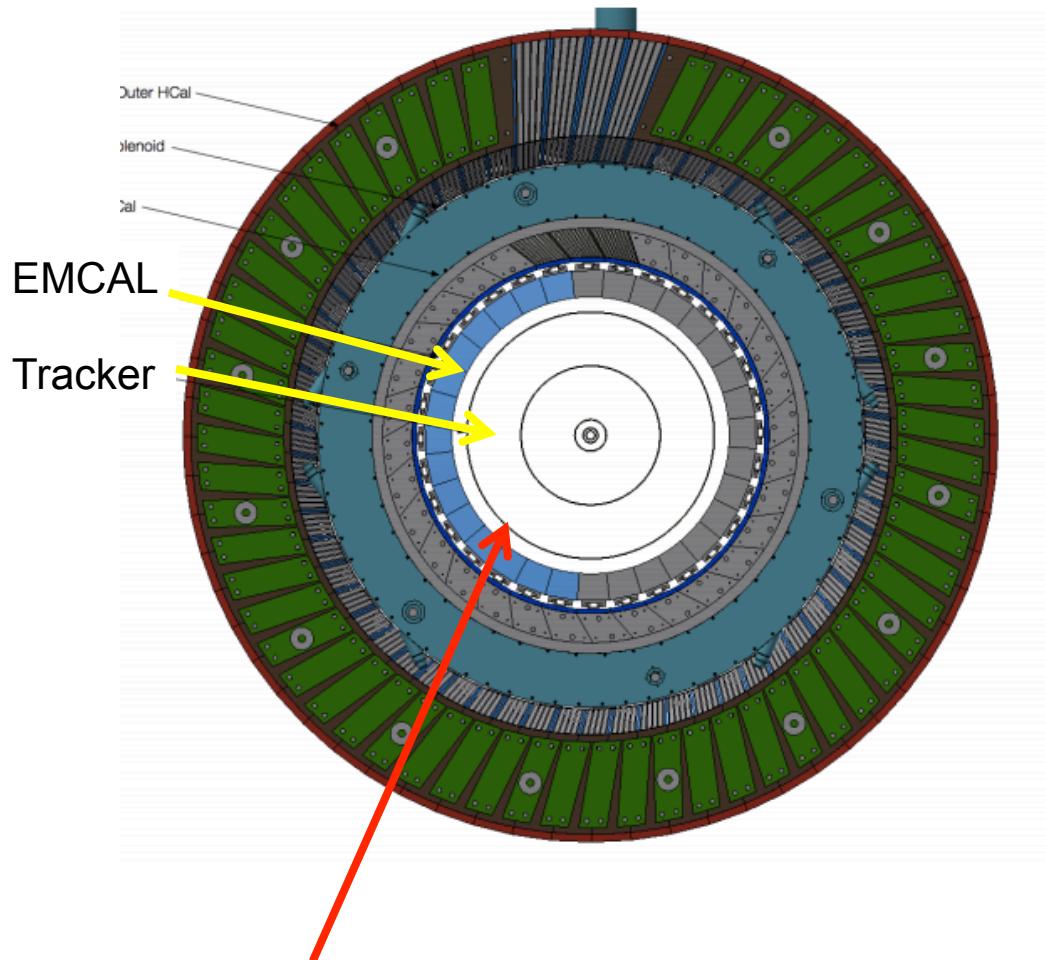
Estimation for Non-prompt D⁰ at sPHENIX



Good performance for measuring non-prompt D^0 at low p_T with sPHENIX

PID detector (TOF) can help further improve the low p_T precision
- constrain the total bbbar X-sec

Particle Identification with TOF



TOF PID requirement:

$$M = p \sqrt{\left(\frac{ct}{L}\right)^2 - 1}$$

$$\frac{\Delta M}{M} = \frac{\Delta p}{p} \oplus \gamma^2 \left[\frac{\Delta L}{L} \oplus \frac{\Delta t}{t} \right] \sim \gamma^2 \frac{\Delta t}{t}$$

STAR TOF:

Radius ~ 2.15 m, $\sigma_t \sim 65$ ps

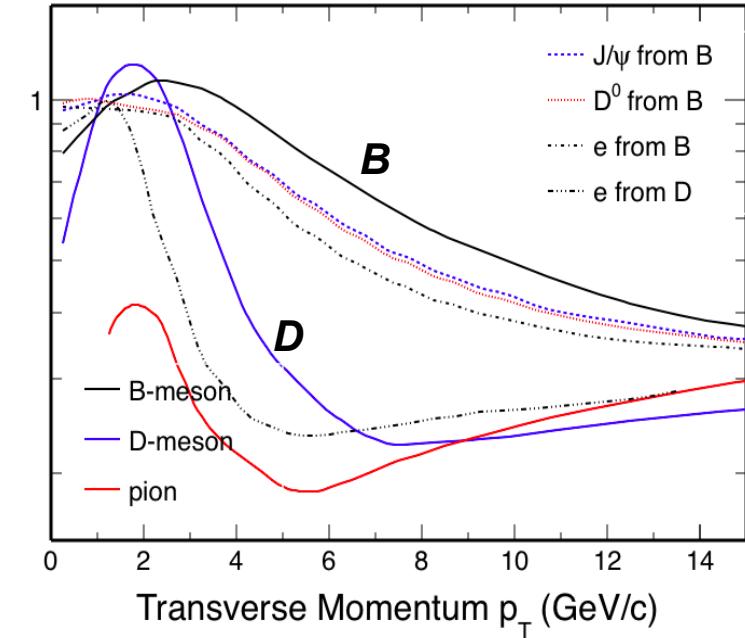
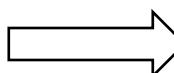
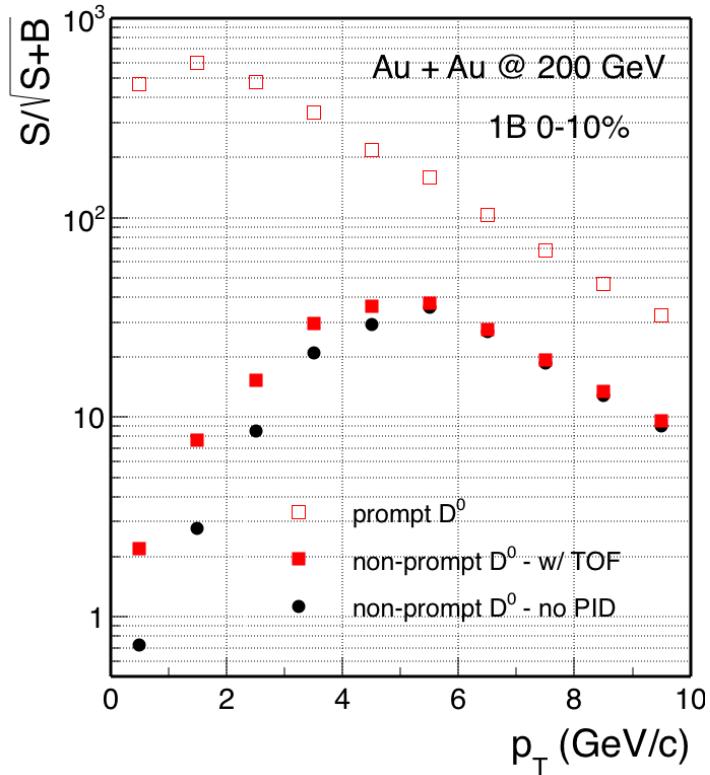
sPHENIX TOF

(to have the same PID capability)

Radius ~ 0.85 m, $\sigma_t \sim 25$ ps

Candidate: Many-gap MRPC

Physics Simulation To-Do List towards Proposal



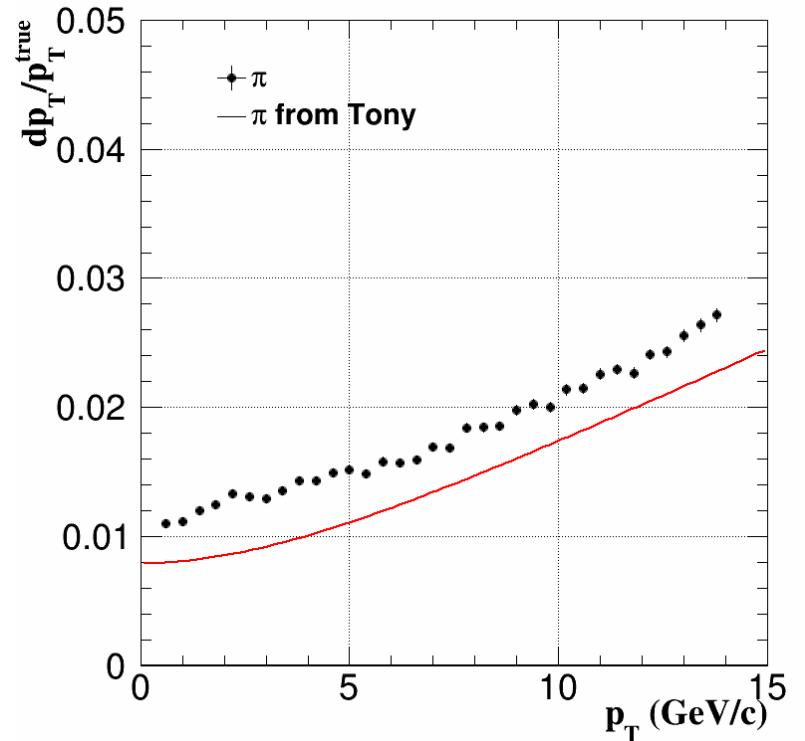
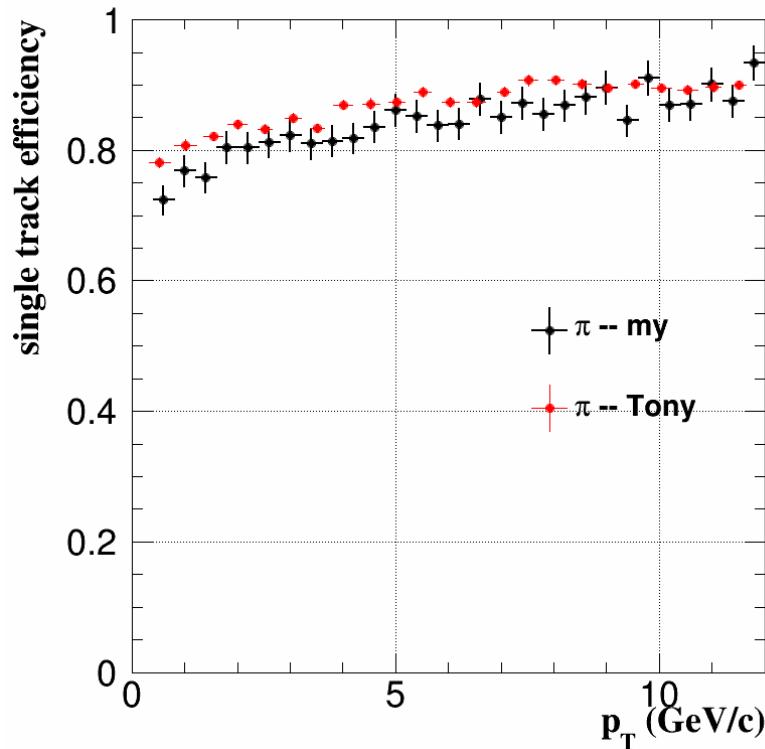
Theory curves on B/D -mesons from TAMU/DUKE/CUJET

- Realistic estimation on the pileup MB/UPC hit density at MAPS sensors.
- Full GEANT simulation to obtain the complete input distributions for data-driven fast simu.
- Estimation of uncertainties on R_{AA}/R_{cp} etc.
 - Vertex resolution/efficiency effect in low multiplicity Au+Au and p+p collisions
- Decay channels $B \rightarrow D$, $B \rightarrow J/\psi$, $B \rightarrow e$ and $B \rightarrow D\pi$ etc.

Other HF measurements, e.g. Λ_c , HQ correlations etc.

Full Simulation Progress

5000 central Hijing events + 30 embedded pi/K/p tracks each
with the latest production configuration



Working on finding the differences and then will follow up on DCA studies

Progress: Billoir Calculation



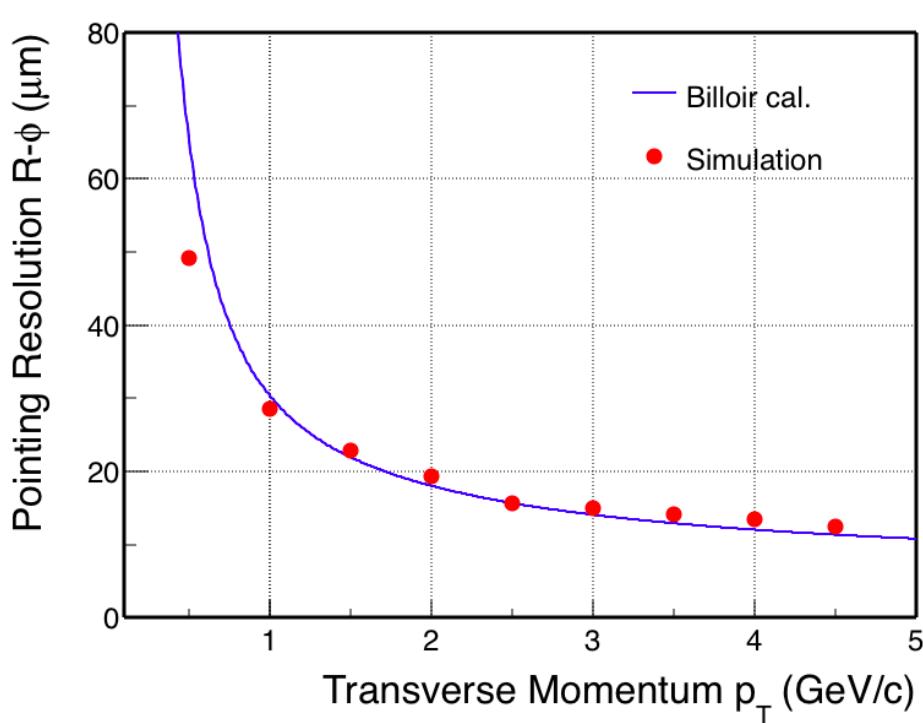
[MCS][D][M][MCS][D] [M][MCS] • • •

P. Billoir NIM 225 (1984) 352

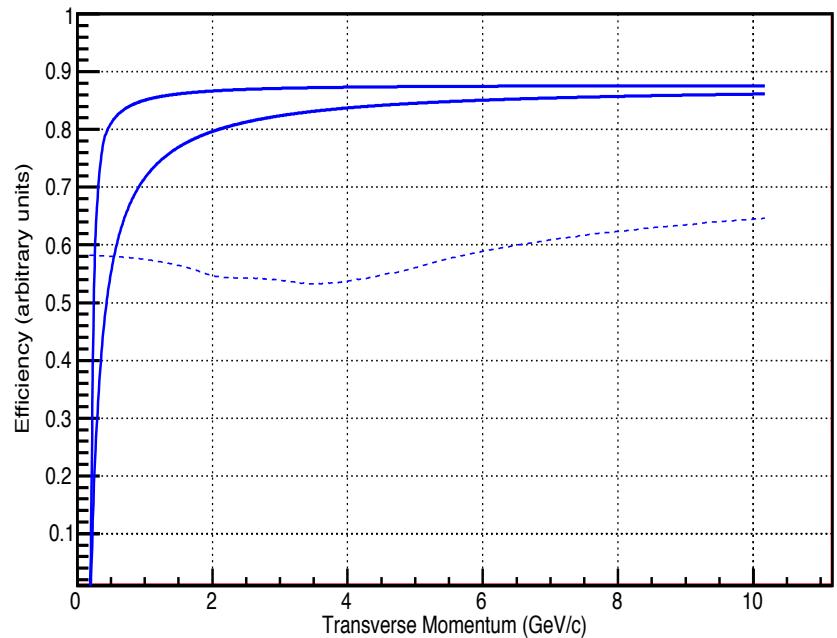
An analytic calculation with inverted matrix for linear Kalman filter method
MCS and dE/dx included
Progressive calculation outside-inside

Layer	Type	Radius (cm)	active thickness	total thickness (X_0)	cell pitch	cell length (in Z)
0	Beampipe	2.0		0.24%		
0	MAPS	2.3	50 μm	0.3%	20 μm	20 μm
1	MAPS	3.2	50 μm	0.3%	20 μm	20 μm
2	MAPS	3.9	50 μm	0.3%	20 μm	20 μm
3	Si strip	6.0	120 μm	1%	80 μm	1.2 cm
4	Si strip	8.0	120 μm	1%	80 μm	1.2 cm
5	Si strip	10.0	120 μm	1%	80 μm	1.2 cm
6	Si strip	12.0	120 μm	1%	80 μm	1.2 cm
7-67*	TPC gas	30-80 cm	50/60 cm	1% ^{+0.2%} _{+1%}	1.5 mm	1.7 mm

Pointing Resolution and Efficiency



Single Track Efficiency for the HFT (D0 Efficiency dashed) .vs. Pt



80×10^{26} RHIC luminosity, central Au+Au 200 GeV collisions

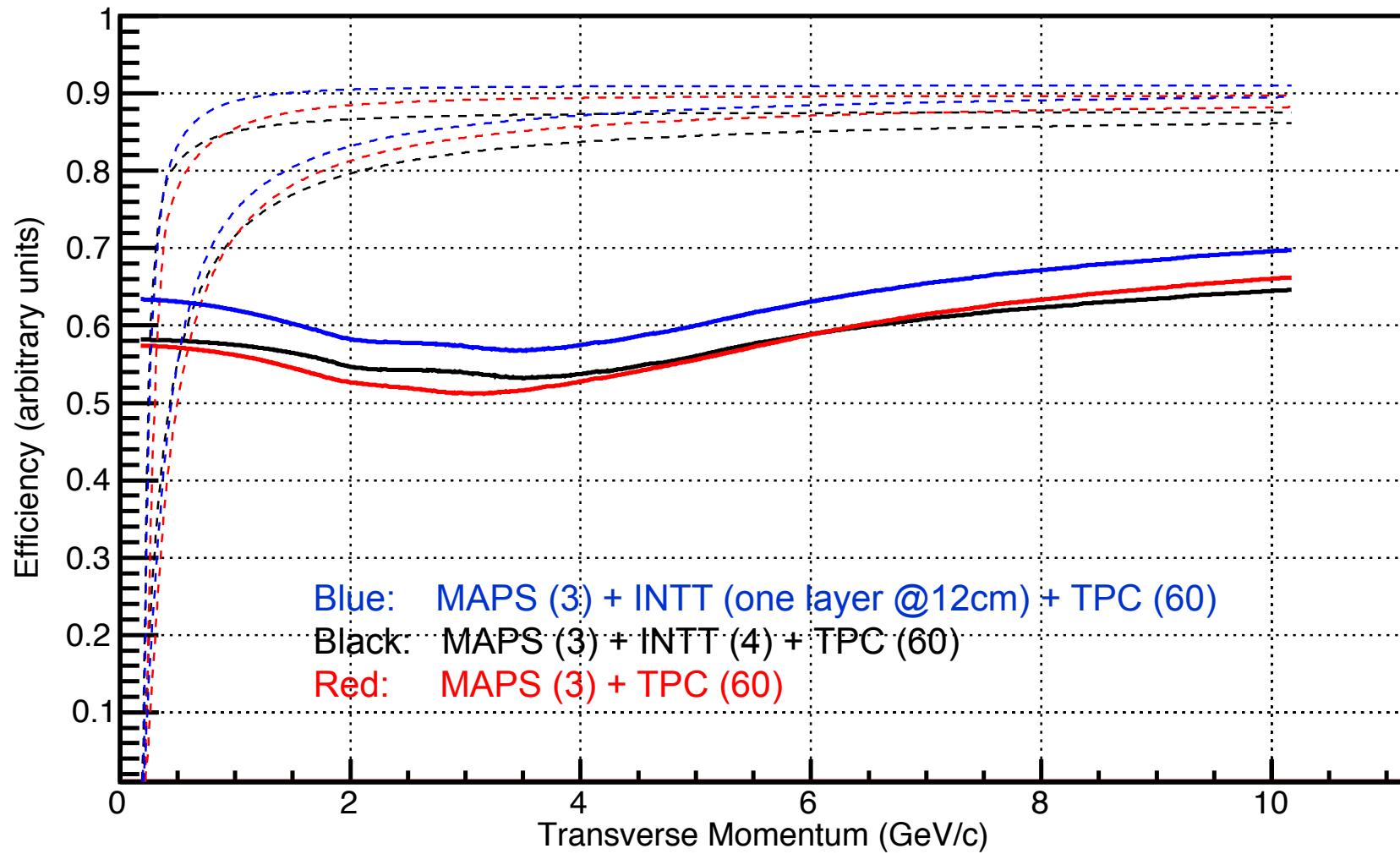
MAPS: 20 us integration time

MB pileup events and UPC hits included (small contribution)

Efficiency or good hit probability: inefficiency due to mis-association

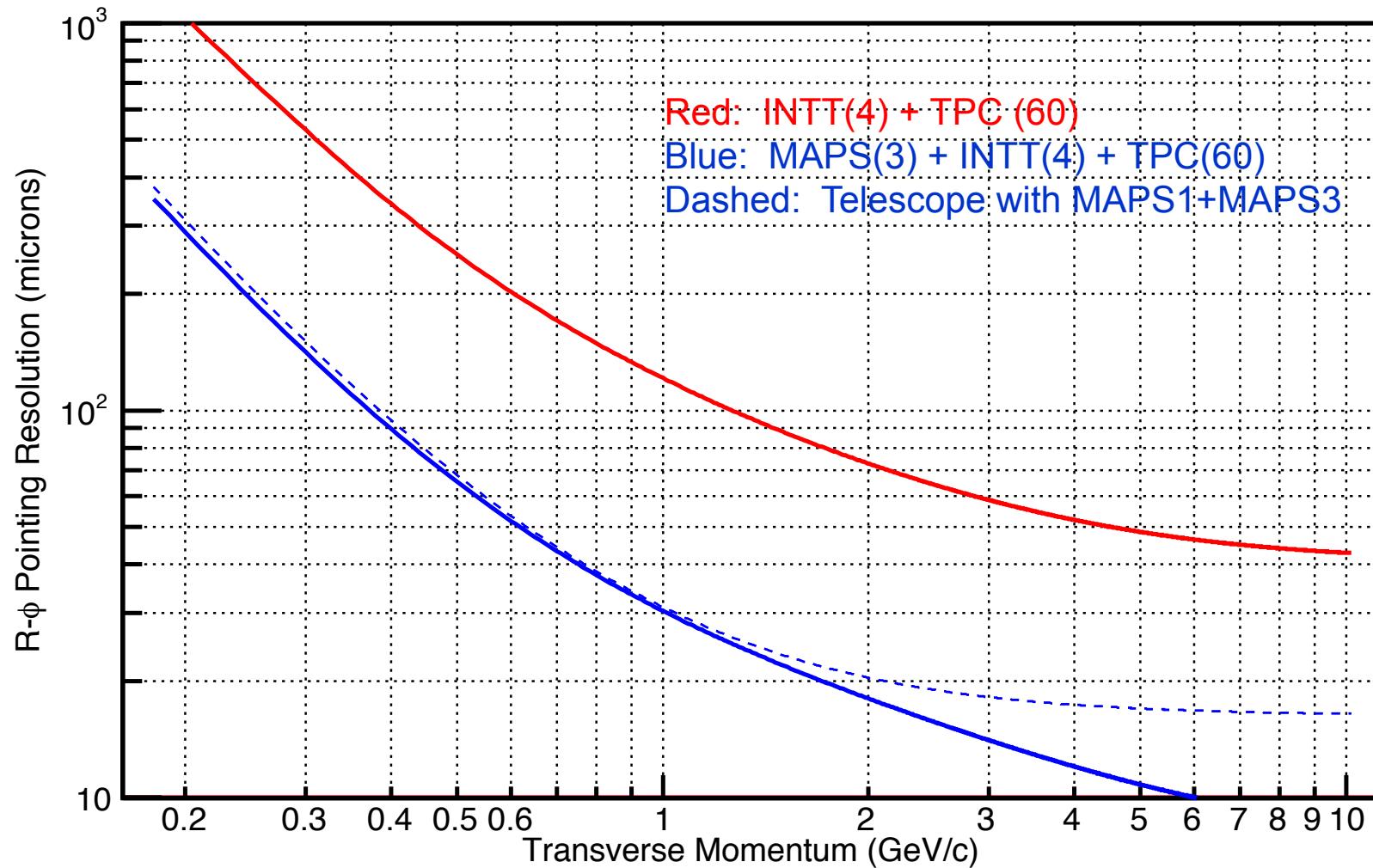
$$\text{Efficiency/Good Hit Probability} = \frac{1}{1 + 2\pi R_{r\phi} R_z \rho} \quad R = \sqrt{R_{proj}^2 + R_{det}^2}$$

Tracking Configuration Study



Tracking Configuration Study

R- ϕ Pointing Resolution .vs. Pt

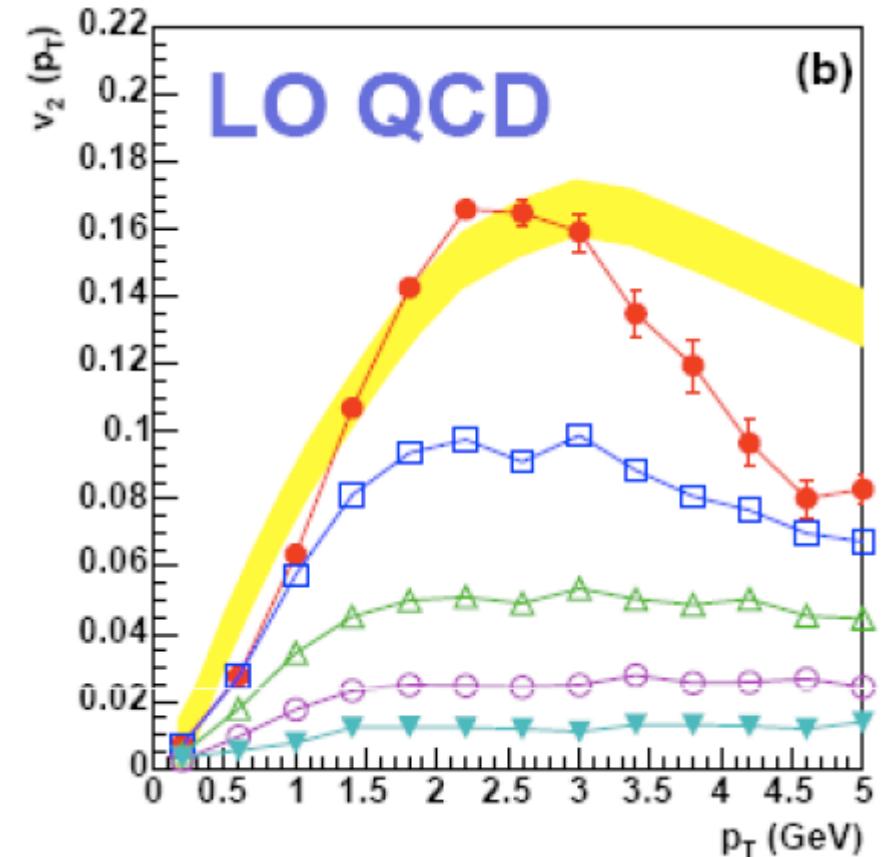
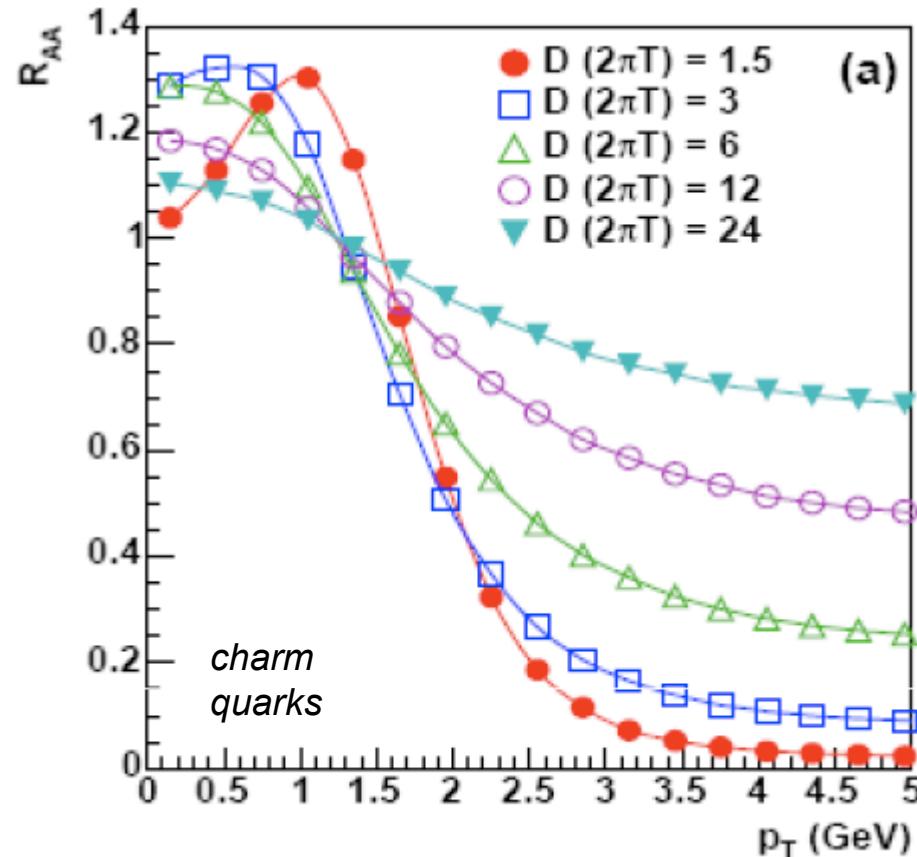


To-Do

- Realistic estimation on the pileup MB/UPC hit density at MAPS sensors.
 - Full GEANT simulation to obtain the complete input distributions for data-driven fast simu.
 - Estimation of uncertainties on R_{AA}/R_{cp} etc.
 - Vertex resolution/efficiency effect in low multiplicity Au+Au and p+p collisions
 - Trigger requirements, particularly in p+p collisions
 - Decay channels $B \rightarrow D$, $B \rightarrow J/\psi$, $B \rightarrow e$ and $B \rightarrow D\pi$ etc.
 - *Billoir calculation for detector configuration studies*
- Other HF measurements, e.g. Λ_c , HQ correlations etc.

Backups

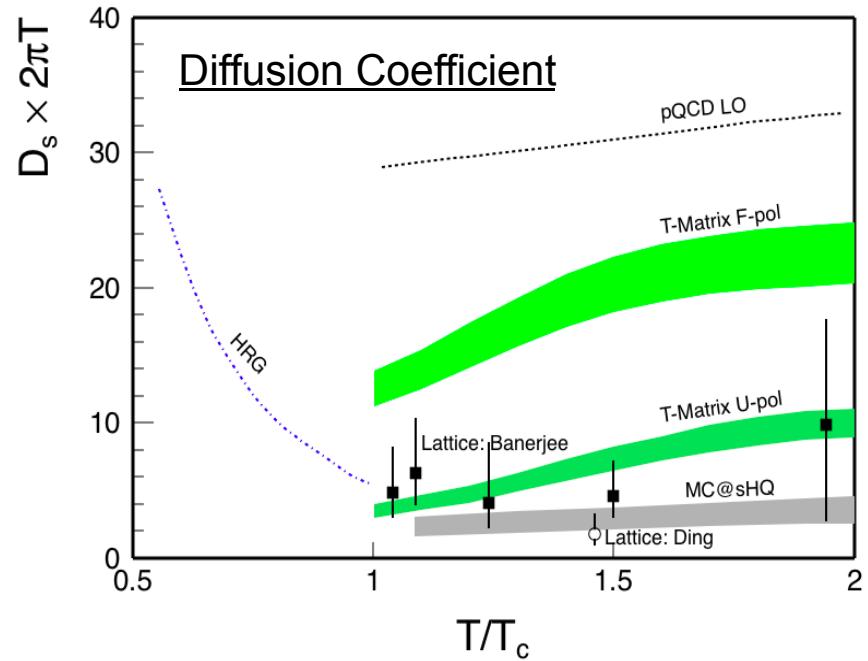
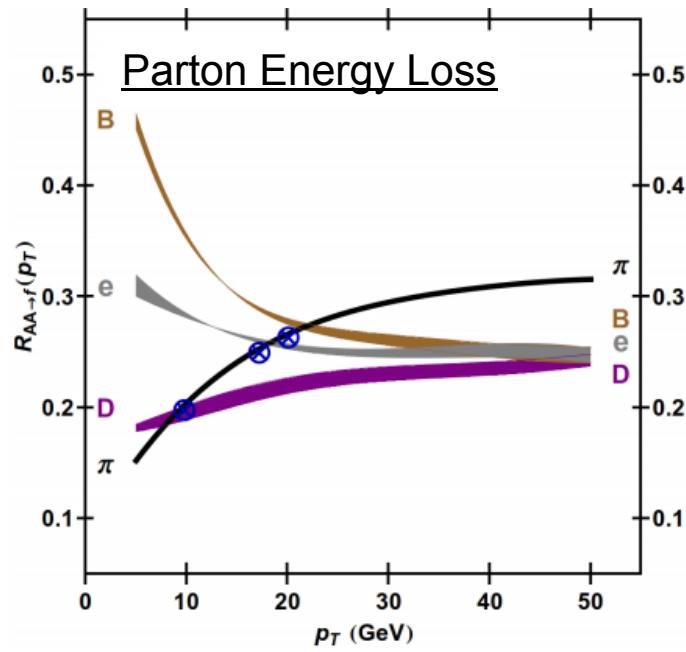
HQ: Sensitive to Medium Transport Parameter



Moore & Teaney, PRC 71 (2005) 064904

Heavy Quarks to Study sQGP Properties

- A) To establish a consistent framework
 - to describe the strongly coupled medium and interactions
 - B) To measure intrinsic transport properties of sQGP medium: D_{HQ} , η/s etc.
- Other Ingredients: p+p reference - pQCD, Cold Nuclear Matter (CNM) effects ...



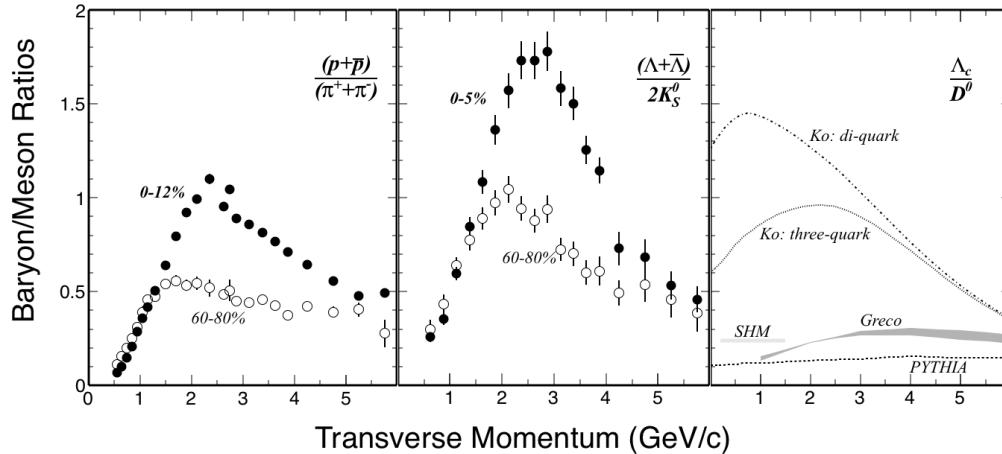
Buzzatti et al., PRL 108 (2012) 022301

arXiv: 1502.02730, 1506.03981

Λ_c and HQ Correlations

High statistics Λ_c measurements

Λ_c/D^0 enhancement sensitive to
 - charm quark hadronization,
 thermalization, domains in sQGP etc.

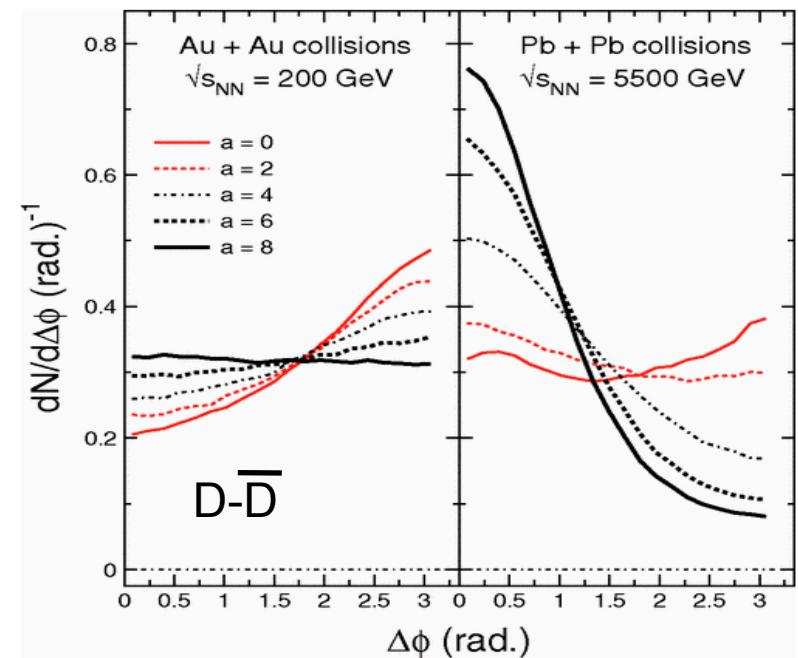


Lee et al, PRL 100 (2008) 222301

Ghosh et al, PRD 90 (2014) 054018

Heavy quark correlations

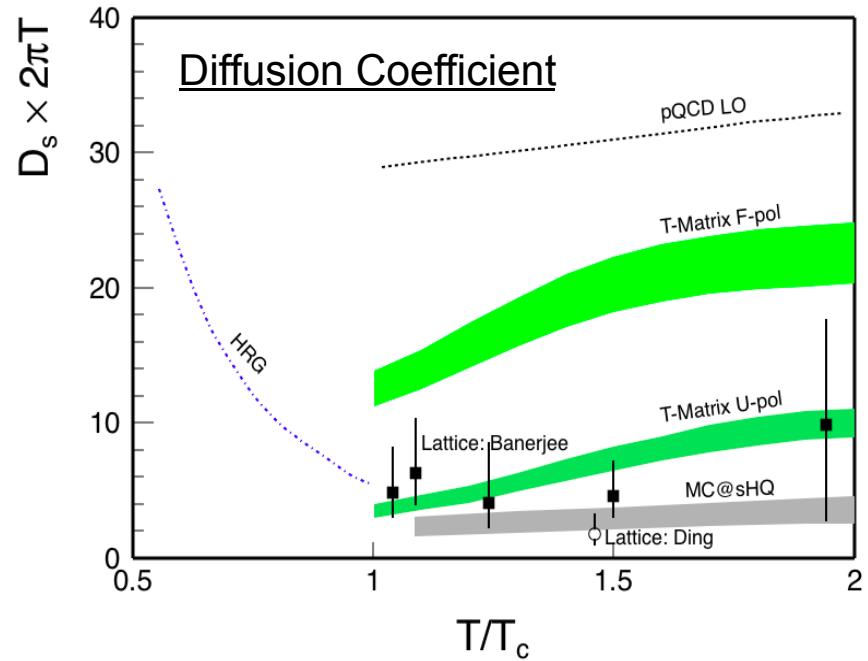
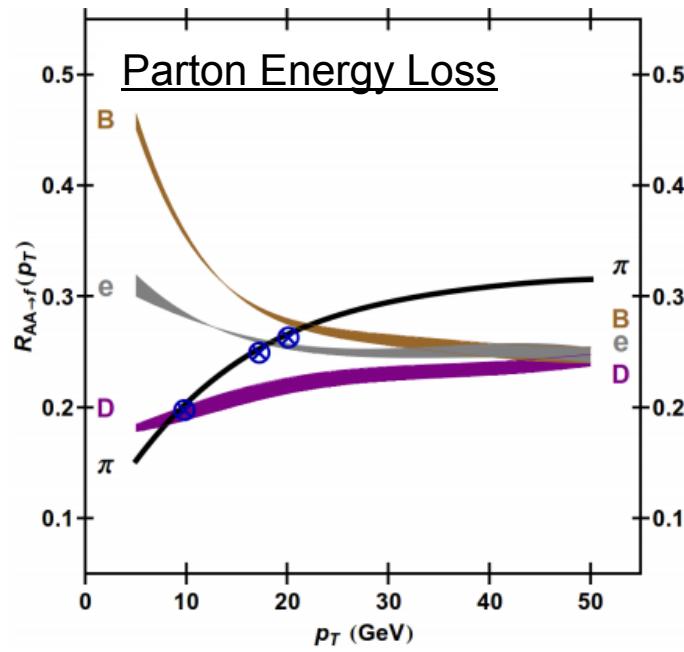
- More sensitivity to HQ-medium interaction, thus better determination of ΔE mechanisms and D_{HQ}
- LHC vs. RHIC – different initial pair correlation/medium dynamics



Zhu et al, PRL 100 (2008) 152301

Summary

- Heavy-flavor phase-I program at RHIC (2014-2016)
 - Precision charmed hadron measurements from STAR-HFT/PHENIX-(F)VTX
- Heavy-flavor phase-II program at RHIC (2021+)
 - Open bottom / correlation measurements
 - Complementary to the HF program at LHC
- Fast MAPS silicon detector is necessary and will deliver the physics



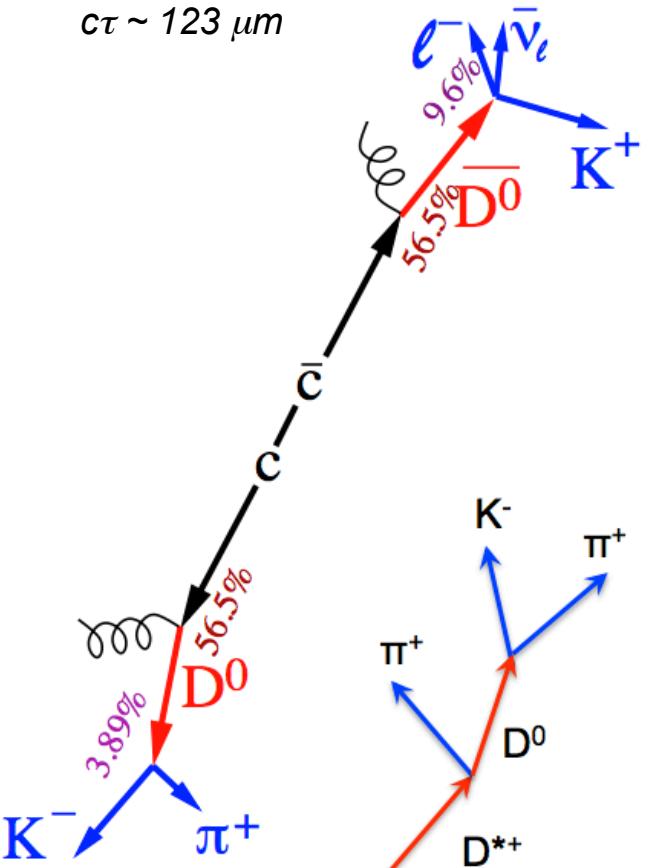
Buzzatti et al., PRL 108 (2012) 022301

arXiv: 1502.02730, 1506.03981

Experimental Challenges

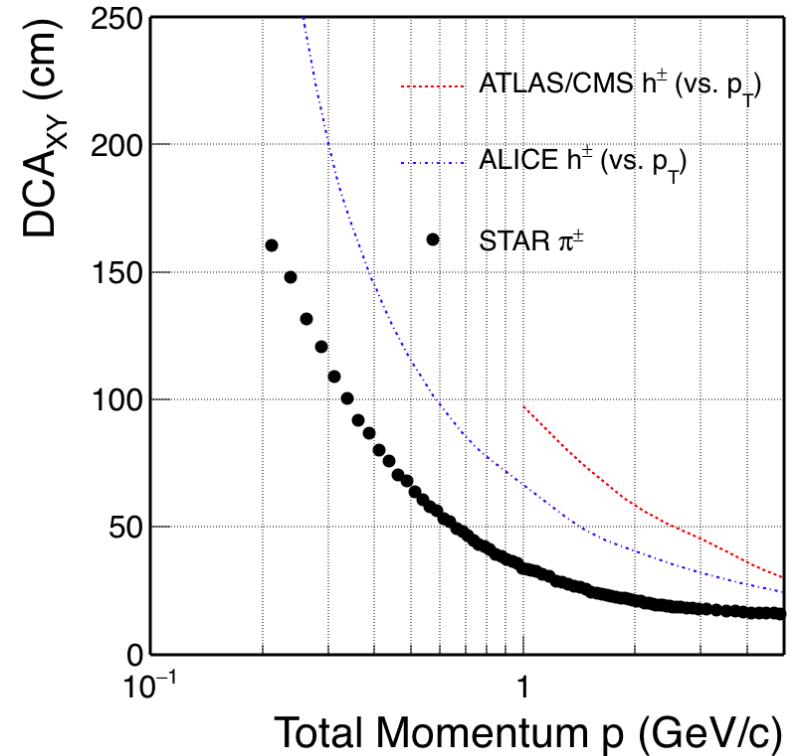
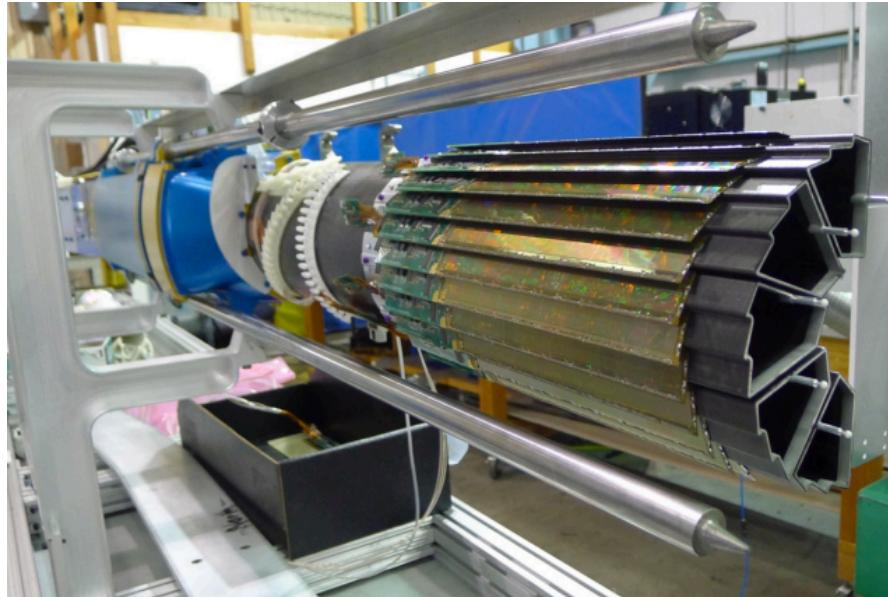
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D_s	10%	150
Λ_c	10%	60
B^+	40%	491
B^0	40%	455
B_s	10%	453
Λ_b	10%	435

Precision vertex detector to reduce combinatorial background is critical for precise measurement



Courtesy: D. Tlusty

STAR Heavy Flavor Tracker



STAR HFT/PXL – first application of MAPS pixel detector at a collider

- Aim for precision measurements of charmed hadron production in HIC
- PXL detector designed, developed and constructed (including mechanics) at LBNL
- First layer thickness: $0.4\%X_0$
- Pitch size $20.7 \times 20.7 \mu\text{m}$
- Integration time: 186 μs (see next page)

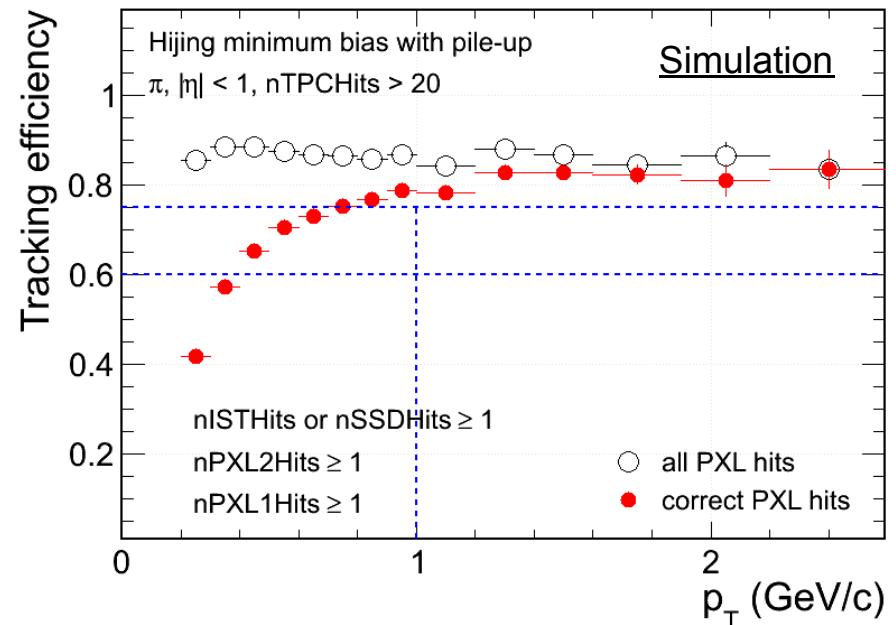
Hit Density on STAR PXL at RHIC Environment

Simulation@50kHz	PXL inner	PXL outer
Radius (cm)	2.8	8
MB pileup hits (cm^{-2})	13	~ 3
UPC electrons (cm^{-2})	33	~ 3
Total bkgd hits (cm^{-2})	46	~ 6
MB signal Au+Au (cm^{-2})	~ 8	~ 1
Au+Au MB real data (cm^{-2})	~ 50	~ 5

Signal hits fraction in MB (Central) events:
 ~15% (~30%) at PXL inner

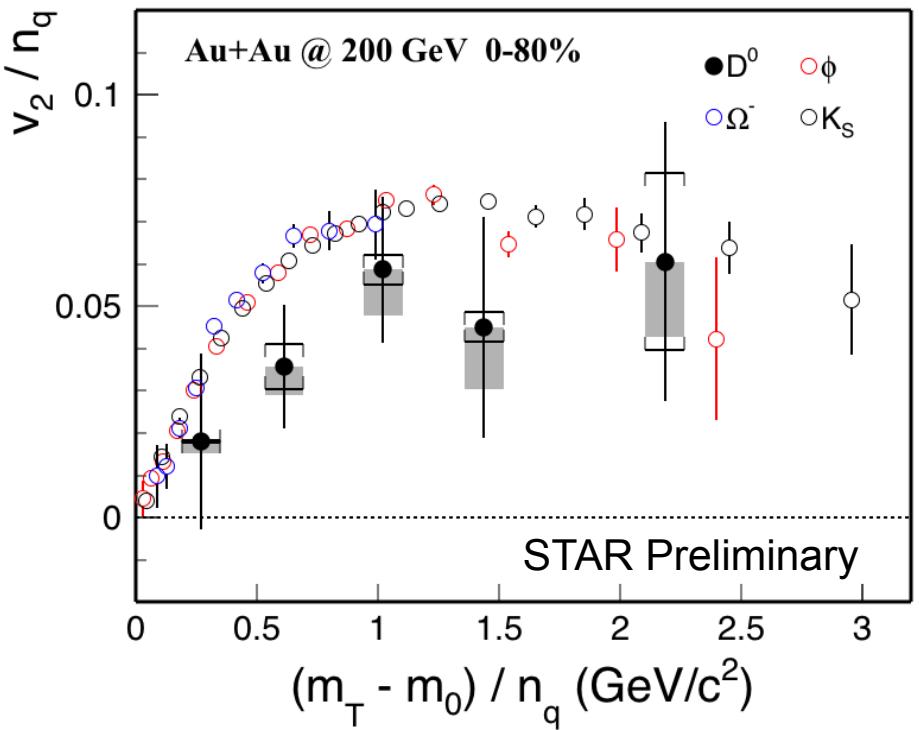
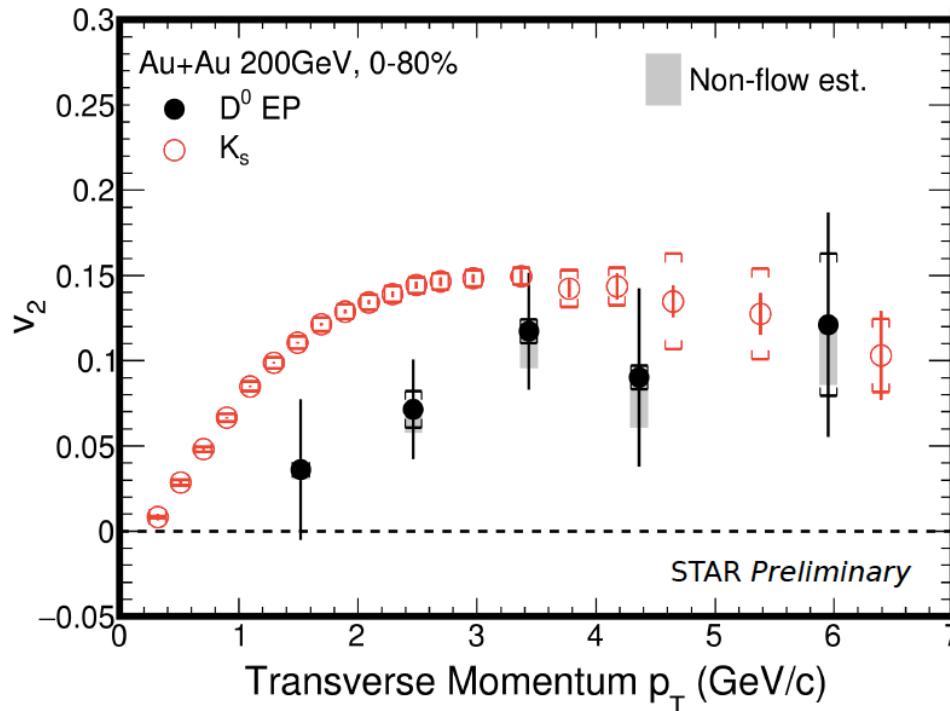
Increasing fake matches in low p_T

Technology chosen considering both
 physics and technology readiness



D-meson v_2 at RHIC

70% of 2014 Au+Au 200 GeV Data



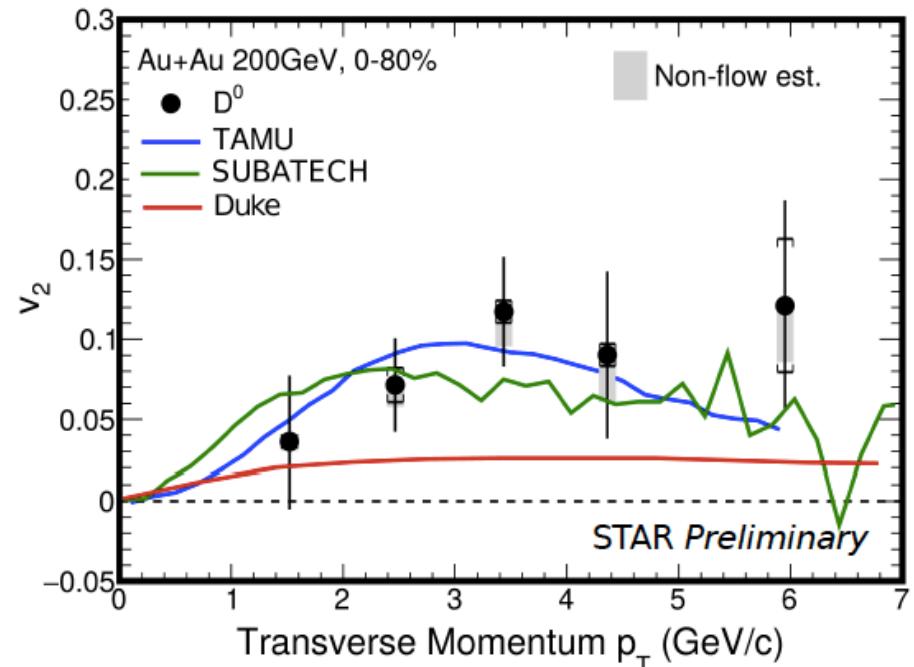
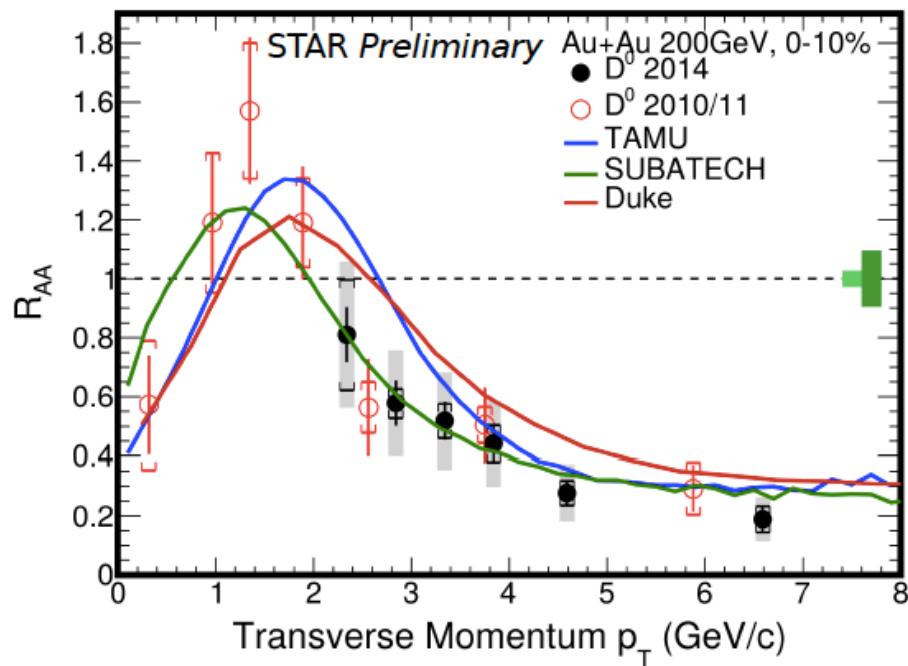
Significant charm hadron v_2 at $p_T > 2$ GeV/c

v_2/n_q vs. $(m_T - m_0)/n_q$: D-meson comparable to K_s , ϕ , Ω

- may be slightly lower: centrality bias

- ($D \sim N_{\text{bin}}$ scaling, light hadrons $\sim N_{\text{part}}$ scaling)

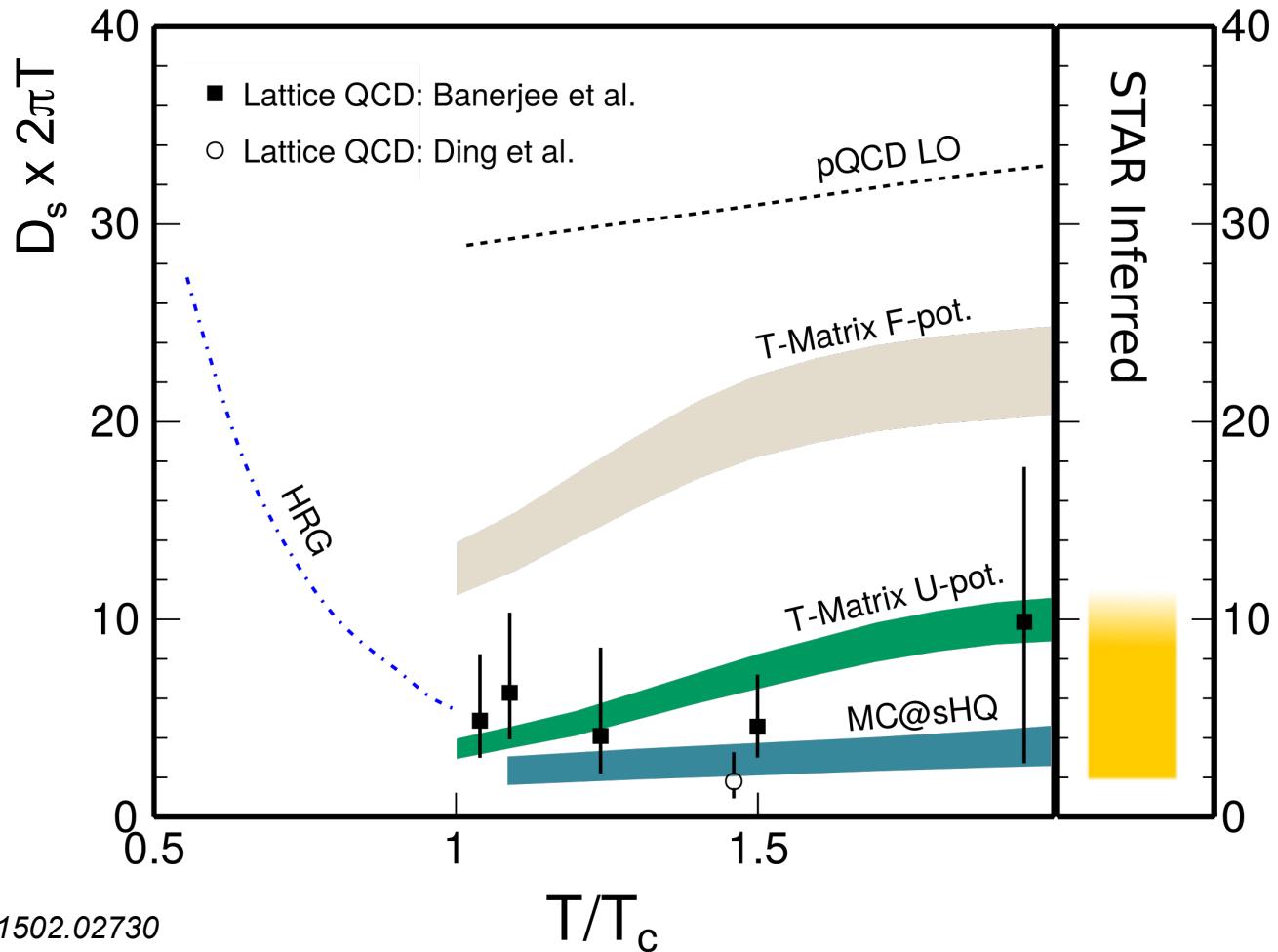
D⁰ R_{AA} and v₂ Compared to Models



D-meson v_2 data favor charm quark diffusion / flow in the medium

Models with **charm flow + coalescence** describe both R_{AA} and v_2 data of D-mesons

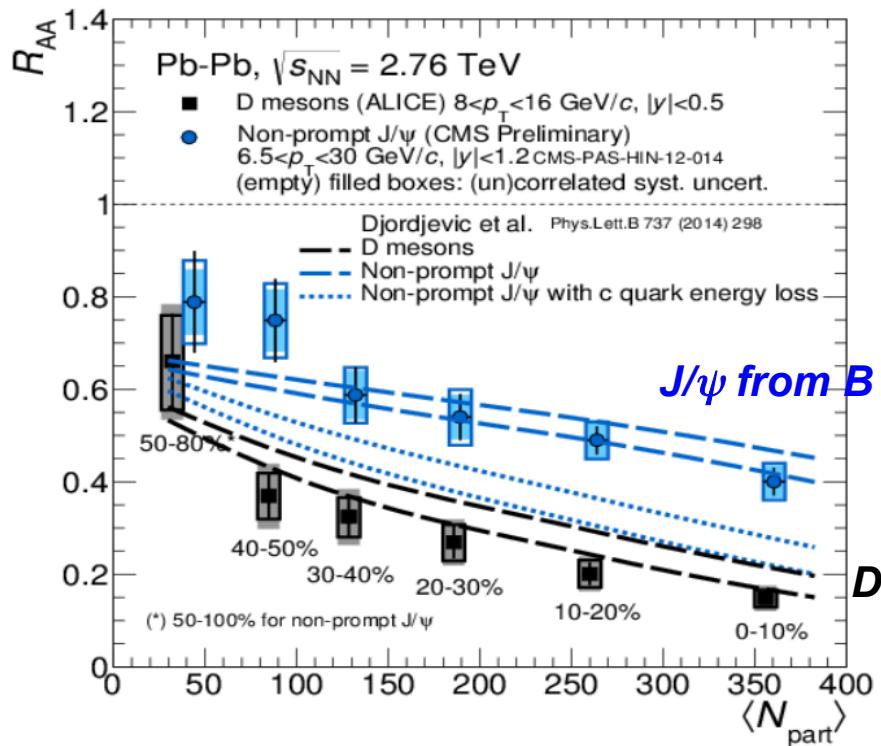
Heavy Quark Spacial Diffusion Coefficient



Data favors $2\pi T D_s \sim 2-12$ (temperature dependence)
- Consistent with lattice QCD calculations

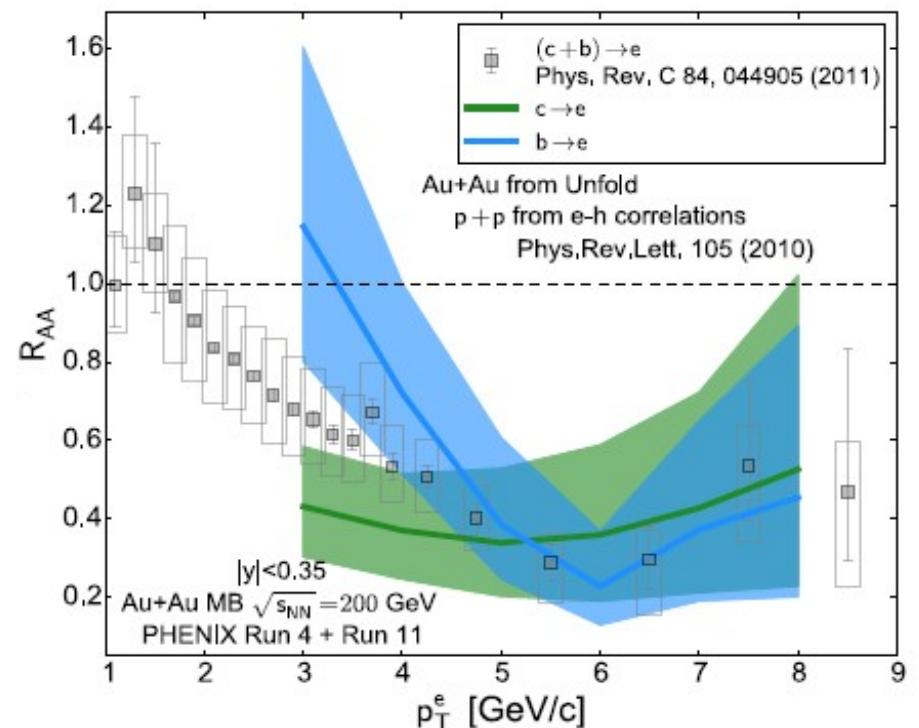
Bottom Suppression in Heavy Ion Collisions

LHC



CMS-PAS-HIN-12-014, ALICE JHEP 11(2015) 205

RHIC



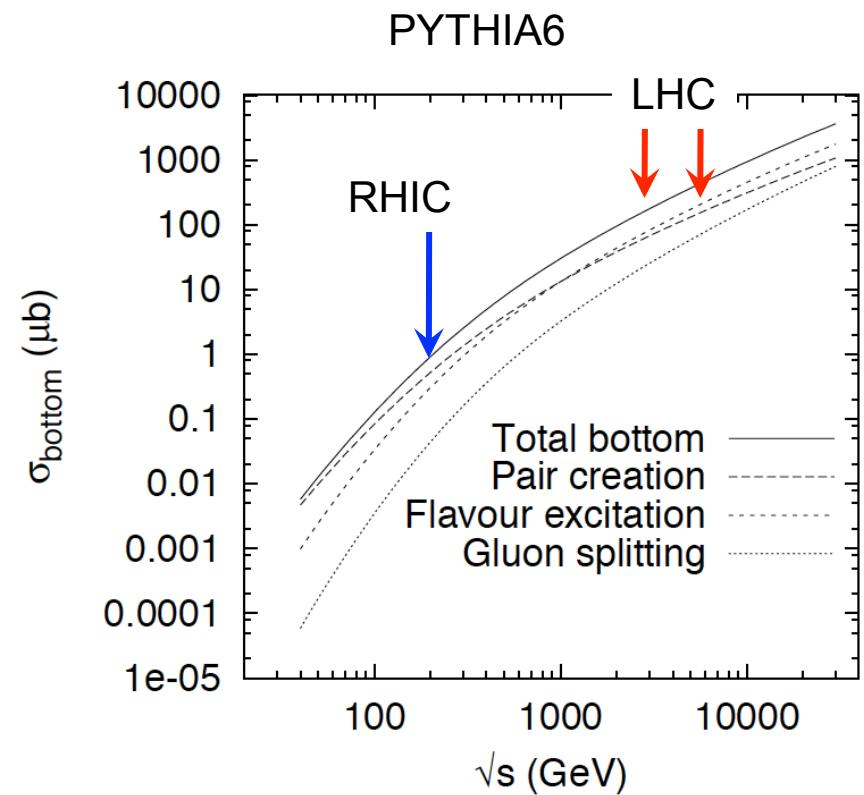
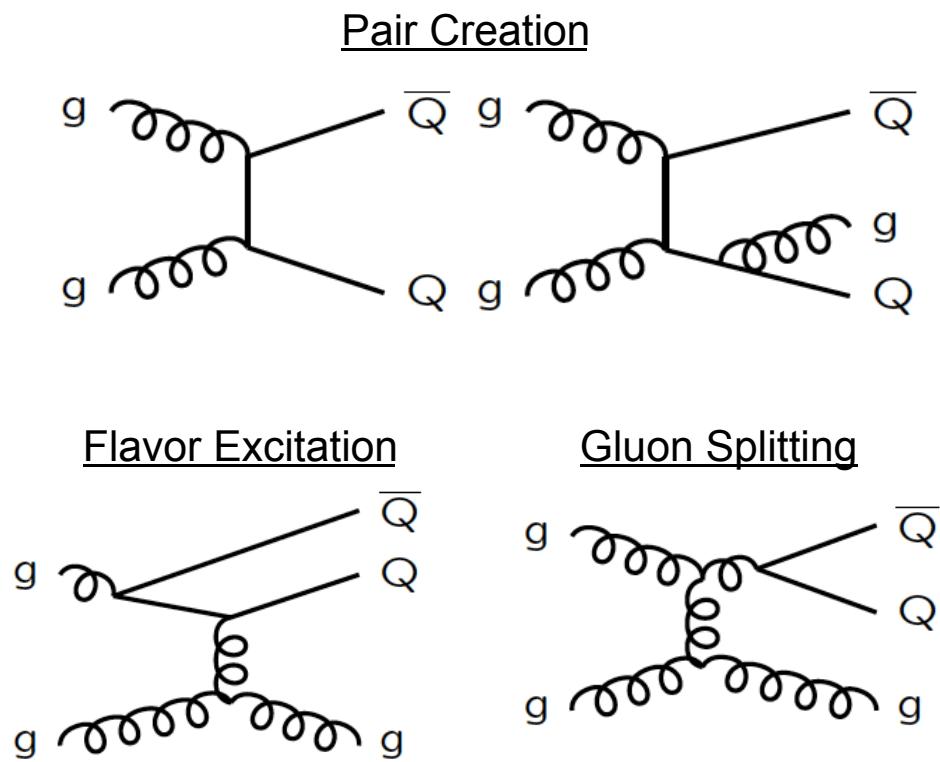
PHENIX PRC 93 (2016) 034904

Suppression hierarchy between $R_{AA}(J/\psi^B)$ and $R_{AA}(D)$ at LHC
Hint of hierarchy between $R_{AA}(e^B)$ and $R_{AA}(e^D)$ at RHIC
– consistent with pQCD calculations

Uniqueness at RHIC

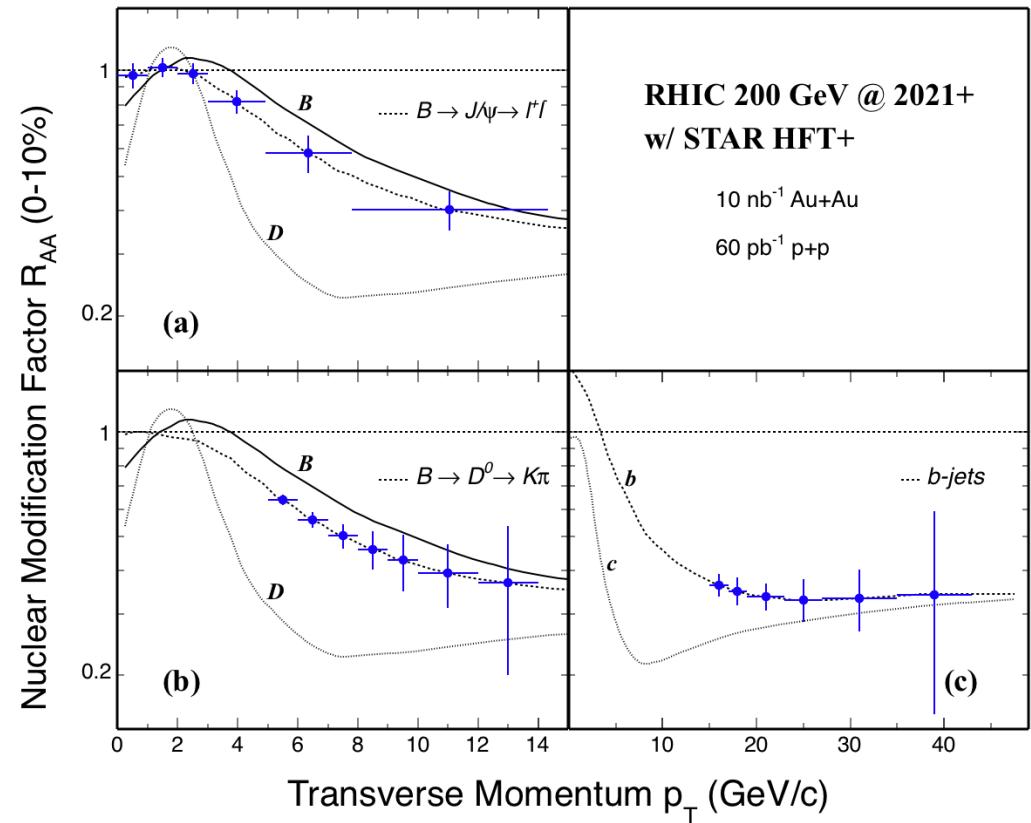
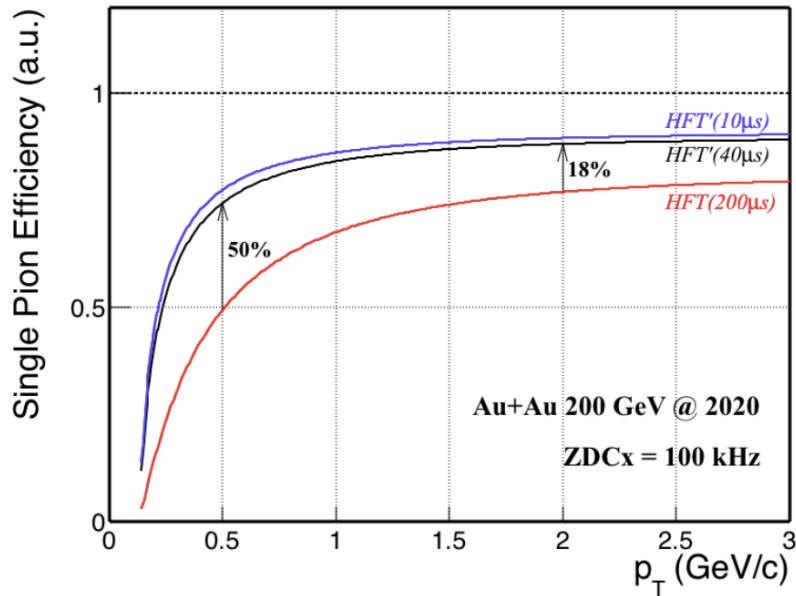
Uniqueness at RHIC

- dominated by pair creation, clean interpretation for experimental results



T. Sjostrand, EPJC17 (2000) 137

Fast MAPS Detectors at RHIC – STAR HFT+



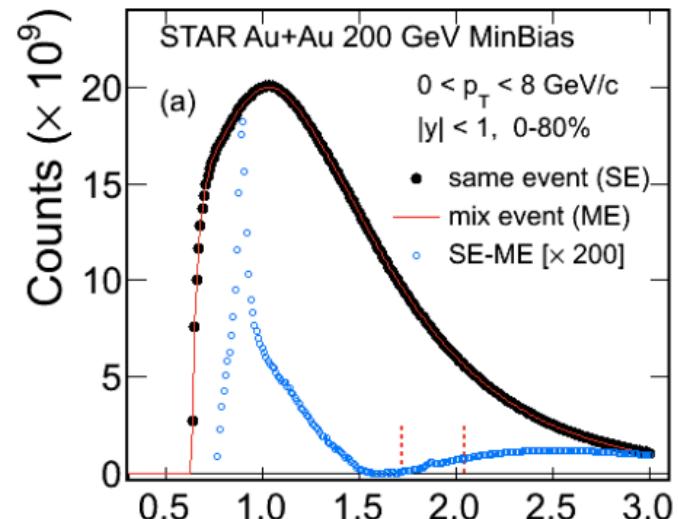
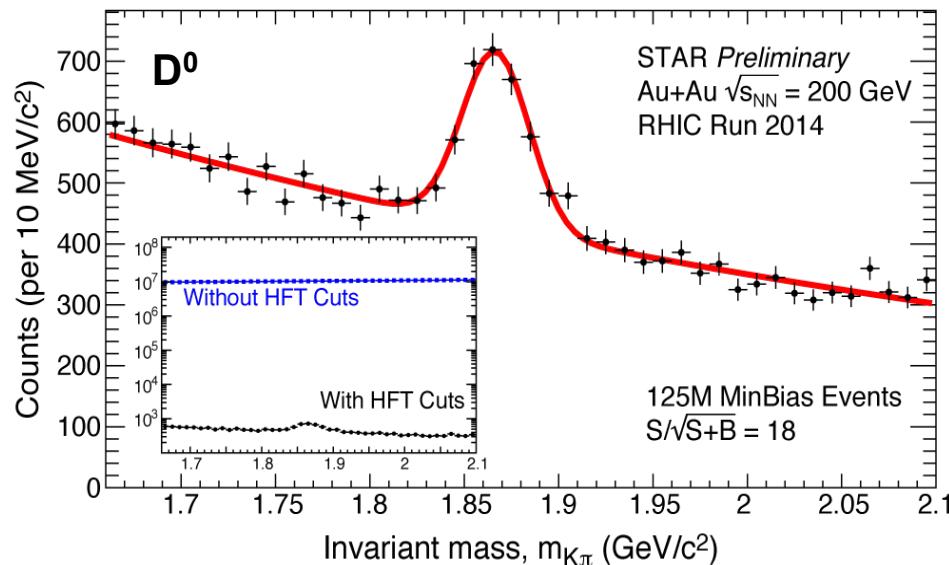
STAR HFT+ upgrade / sPHENIX pixel detector:

- Faster ($<20\mu\text{s}$) MAPS sensors – benefiting from ALICE ITS upgrade
- Aim for precision bottom measurements in 2021+ at RHIC

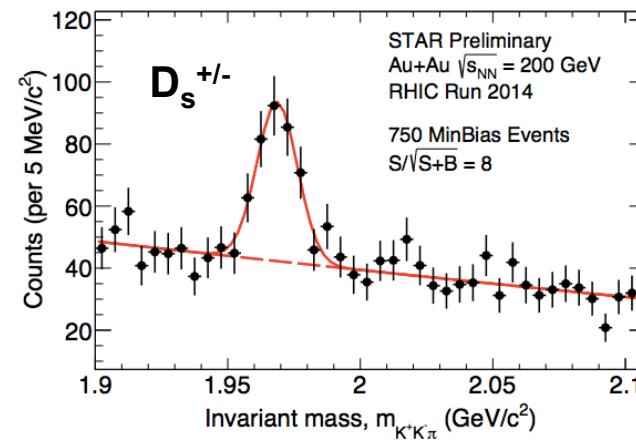
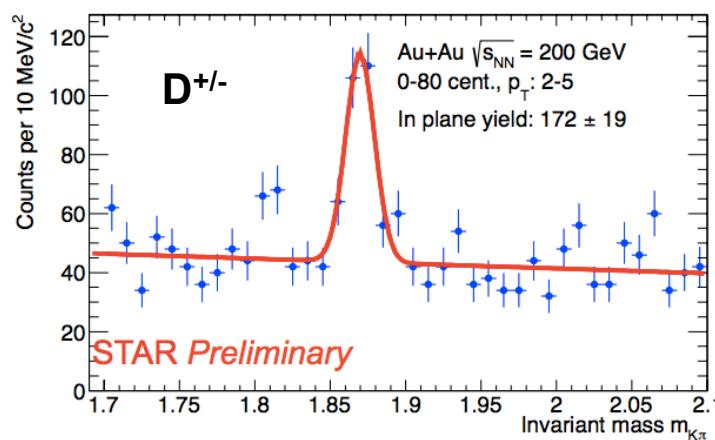
Complementary to LHC heavy flavor program

Pixel Detector Performance

STAR, PRL 113 (2014) 142301



Significant improvement in S/B in D-meson reconstruction

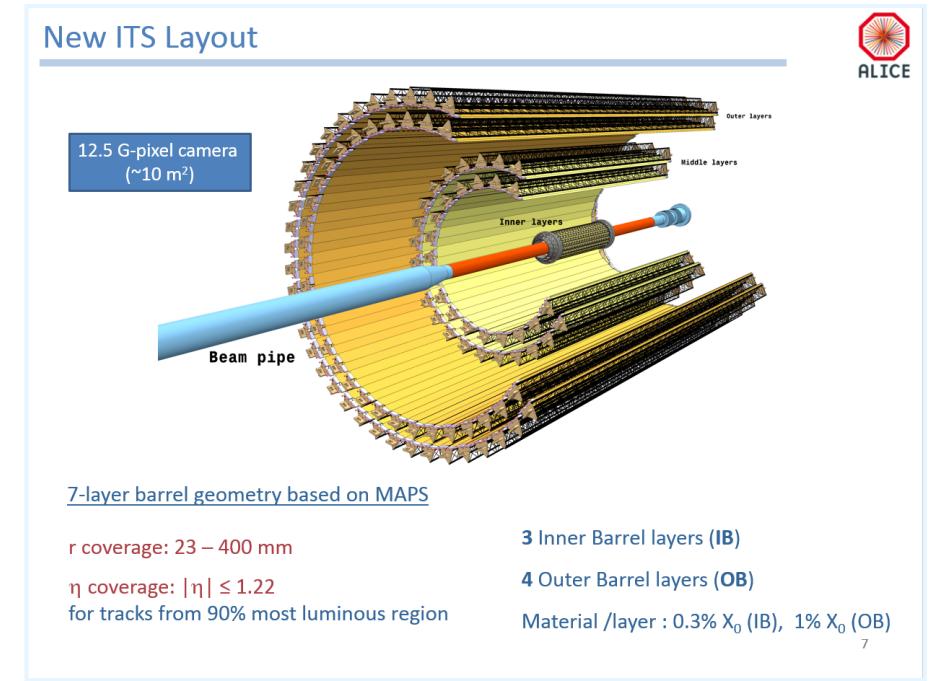


Technology – ALICE MAPS for ITS-upgrade

ALPIDE full-scale prototype ver.3 (Oct 2015)

Main parameters

- Dimensions: 30mm x 15 mm
- Pixel pitch: 29 μm x 27 μm
- Power consumption <100mW/cm²
- Material thickness: 0.3X₀ (inner), 1X₀ (outer)
- Integration time: < 20 μs
- Total area 10 m² (PXL was 0.16 m²)



LBNL RNC group is the project leader for the ALICE-USA ITS upgrade construction project.

- Assembly and testing of Middle layer staves (layers 3,4)
- RDO system design (collaboration) and fabrication of RDO for the middle layers.
- Design of the powering system for all outer layers (3-6)
- Sensor and component testing at the BASE facility for SEU and SEL.
- Outer layers carbon fiber support cylinder and services cone structures.

D-meson R_{AA} and v_2 : RHIC vs. LHC

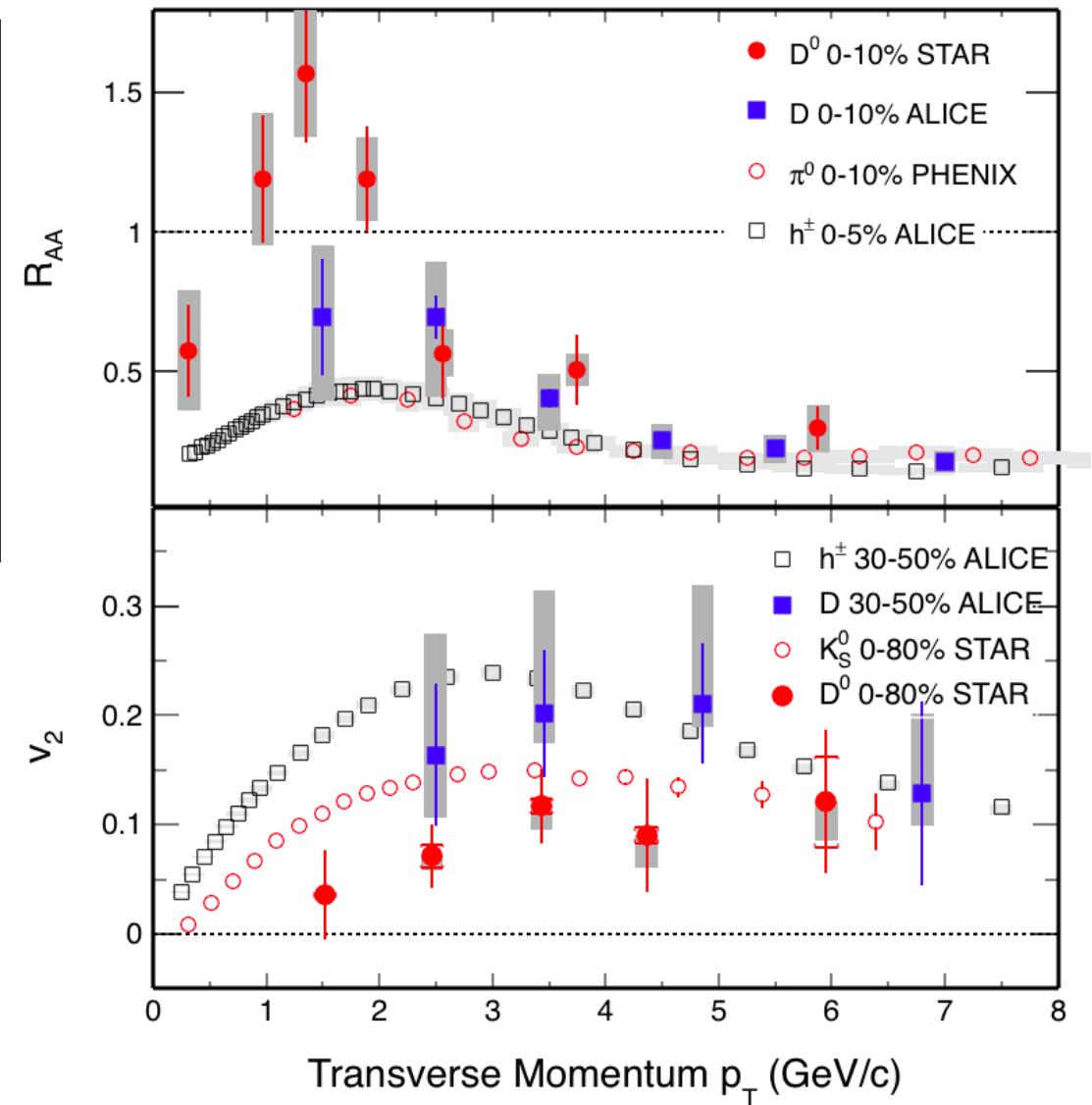
Comparable suppression at high p_T

- collisional and radiative ΔE

Possibly different physics at low p_T

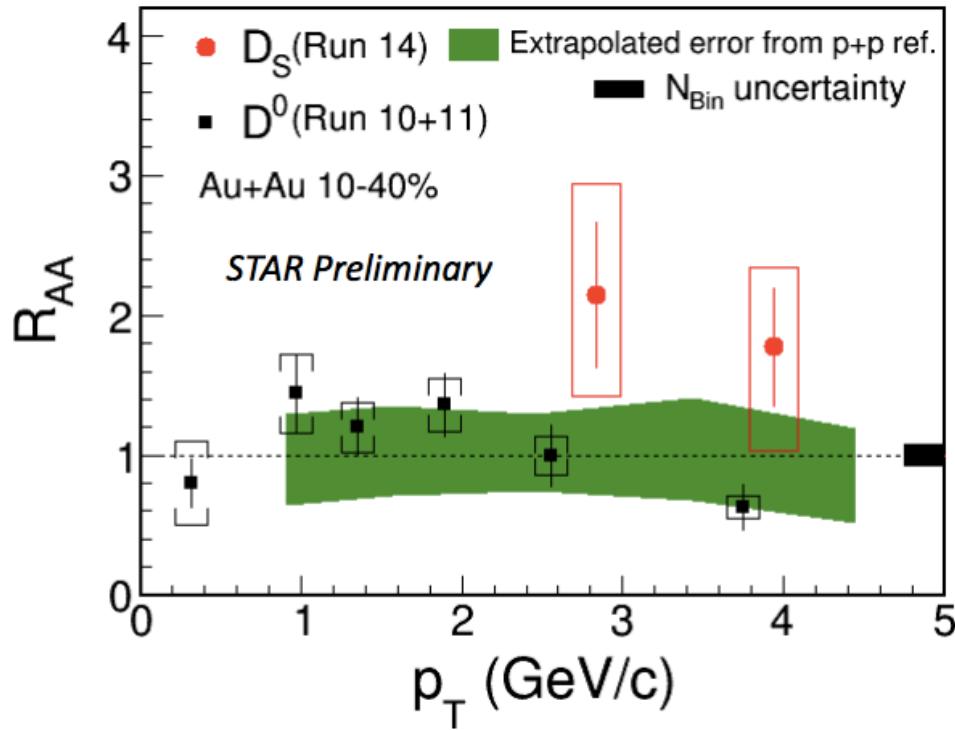
- Initial parton distributions
 x_T at 2 GeV/c $\sim 10^{-2}$ (RHIC)
 $\sim 10^{-3}$ (LHC)
- “Cronin” effect
- Charm quark flow

Precision charm v_2 data,
particularly to low-intermediate
 p_T are critical for the extraction
of sQGP D_{HQ} .

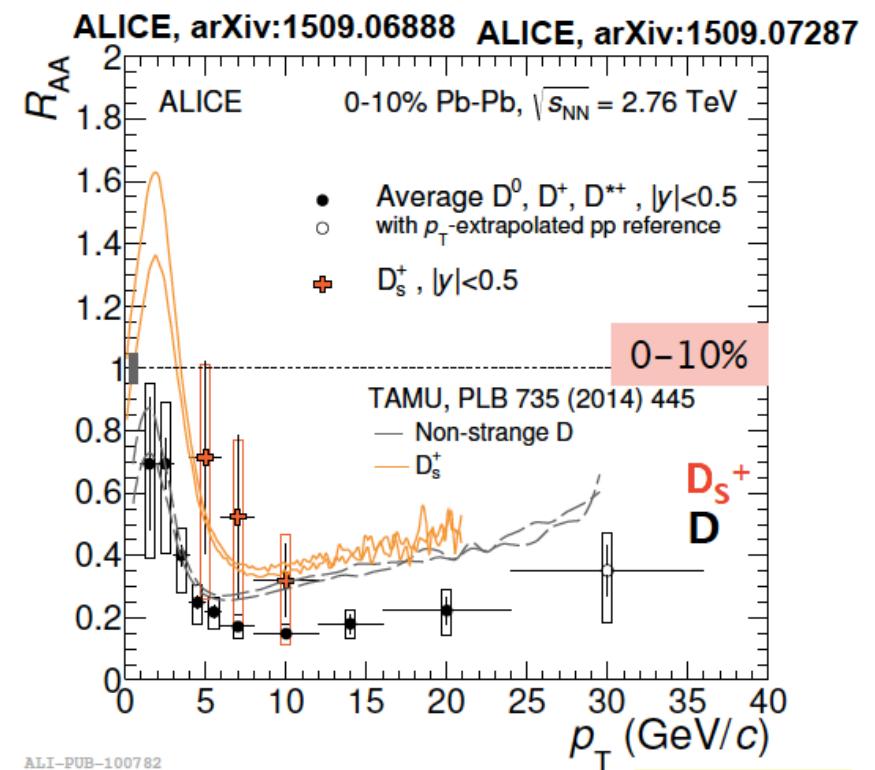


D_s – Hadronization and Strangeness Enhancement

RHIC



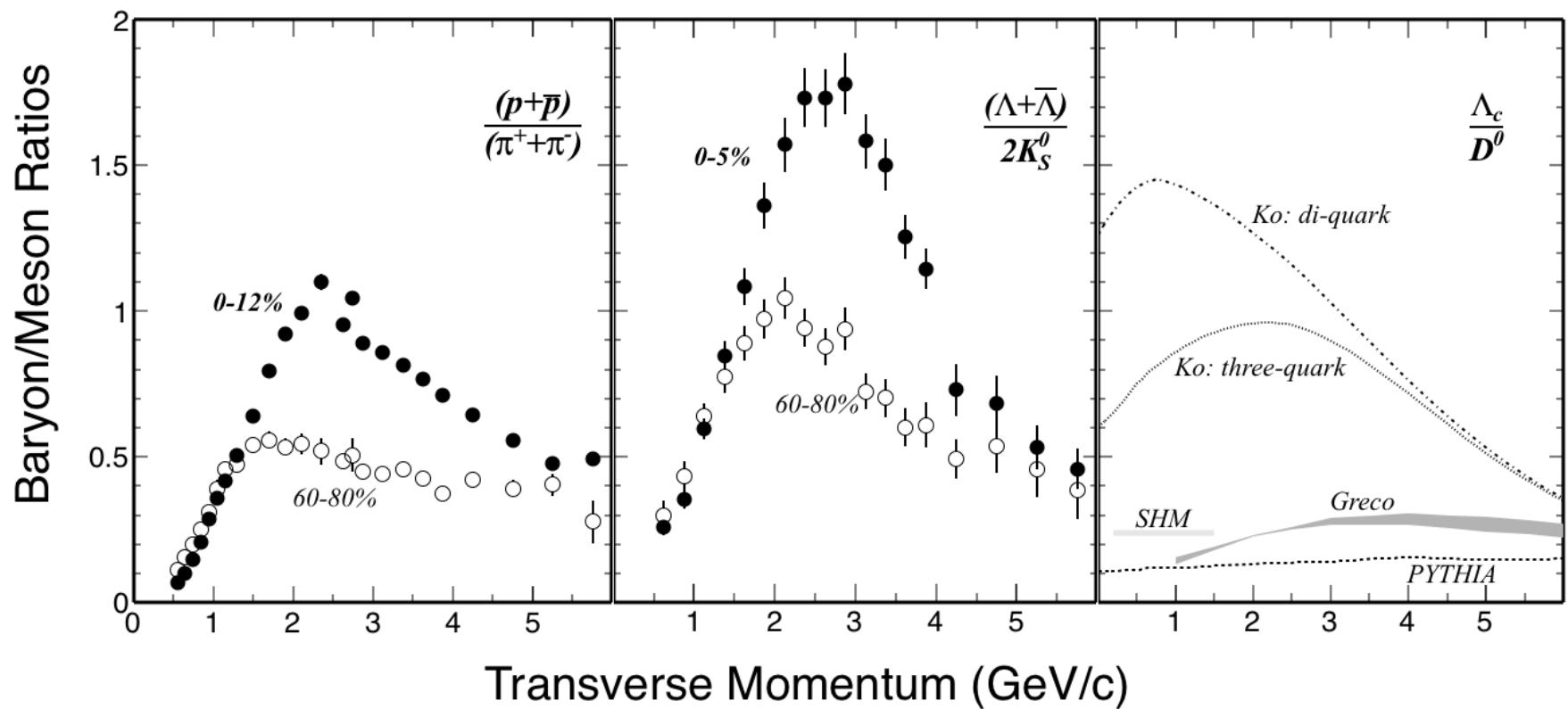
LHC



Strangeness enhancement in QGP + coalescence $\rightarrow D_s/D^0$ enhancement in HI collisions

Hint of D_s/D^0 enhancement in data from RHIC and LHC \rightarrow need more precise measurements

Λ_c - Charm Baryon Enhancement?



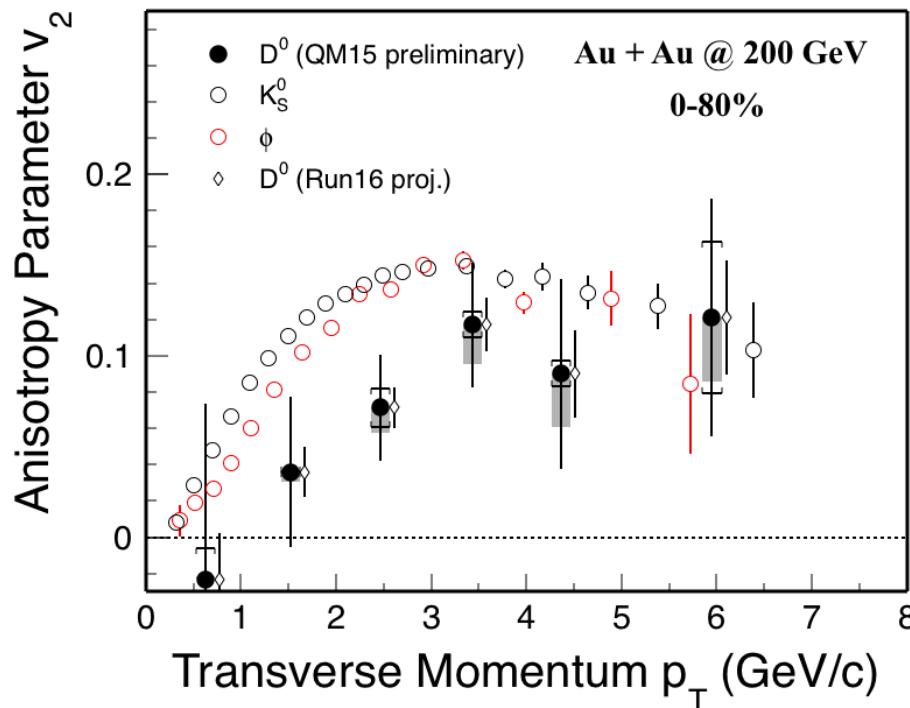
Various models predict different levels of enhancement for Λ_c/D^0 depending on
- hadronization, thermalization, domains in sQGP

No measurement of Λ_c in A+A collisions ($c\tau \sim 60 \mu\text{m}$, $\Lambda_c^+ \rightarrow p K^- \pi^+$, B.R. 5%)

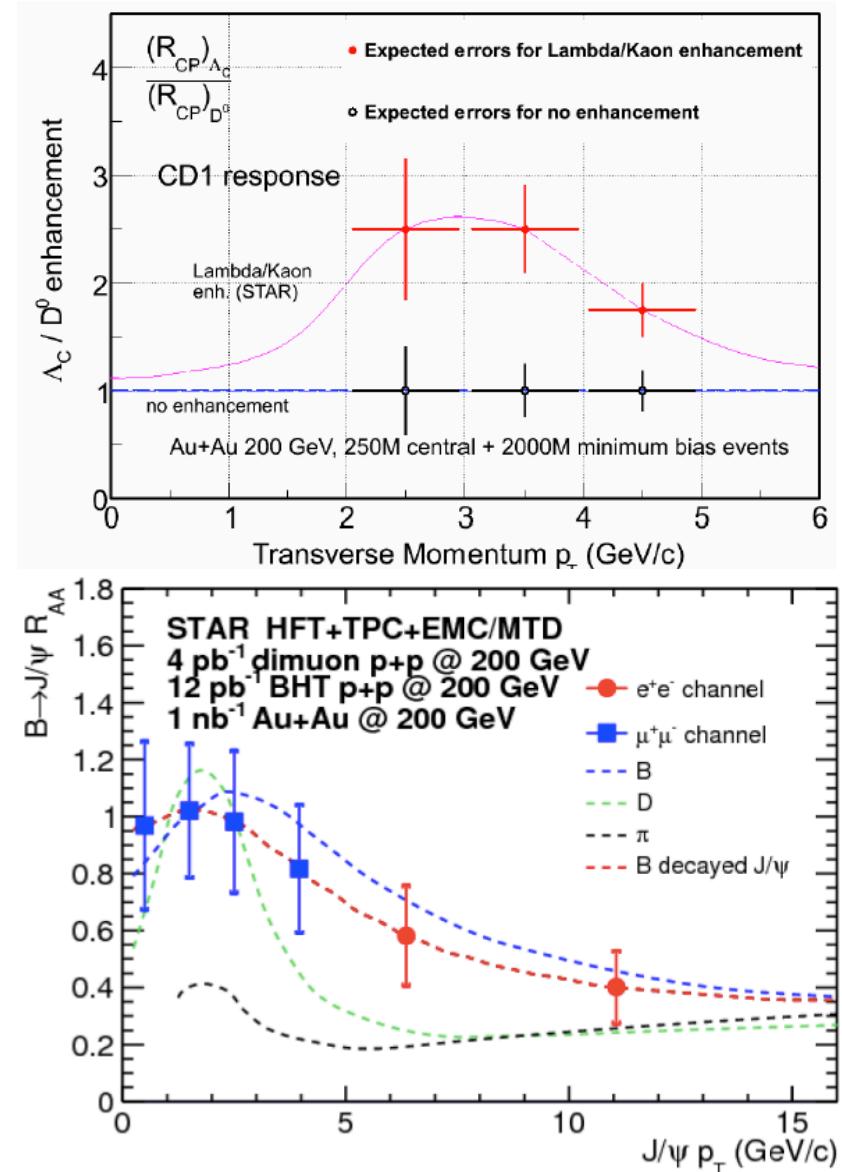
Prospective with the STAR HFT data at RHIC

Λ_c/D^0 : Lee et al., PRL100 (2008) 222301; Ghosh et al., arXiv:1407.5069

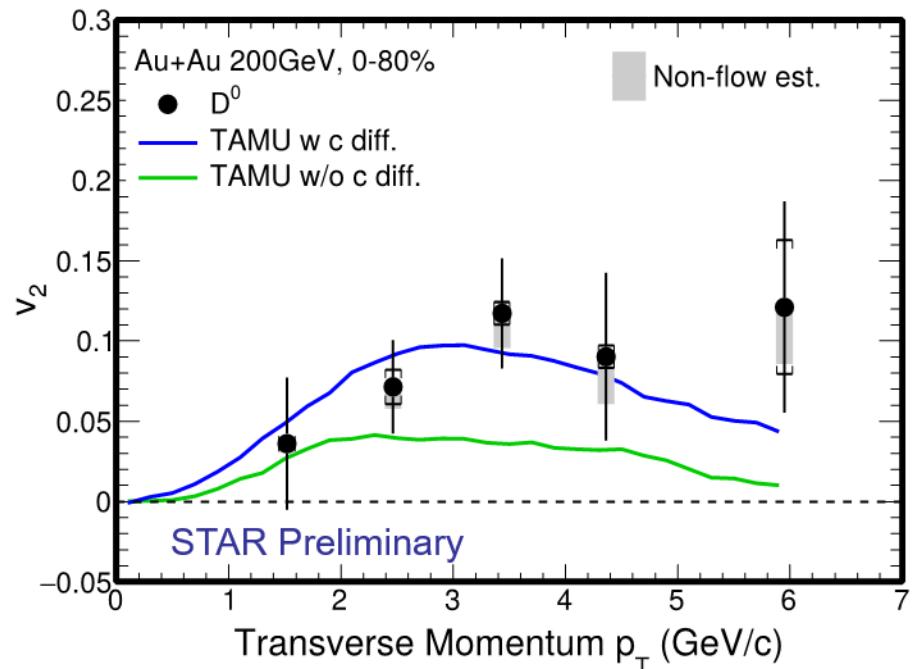
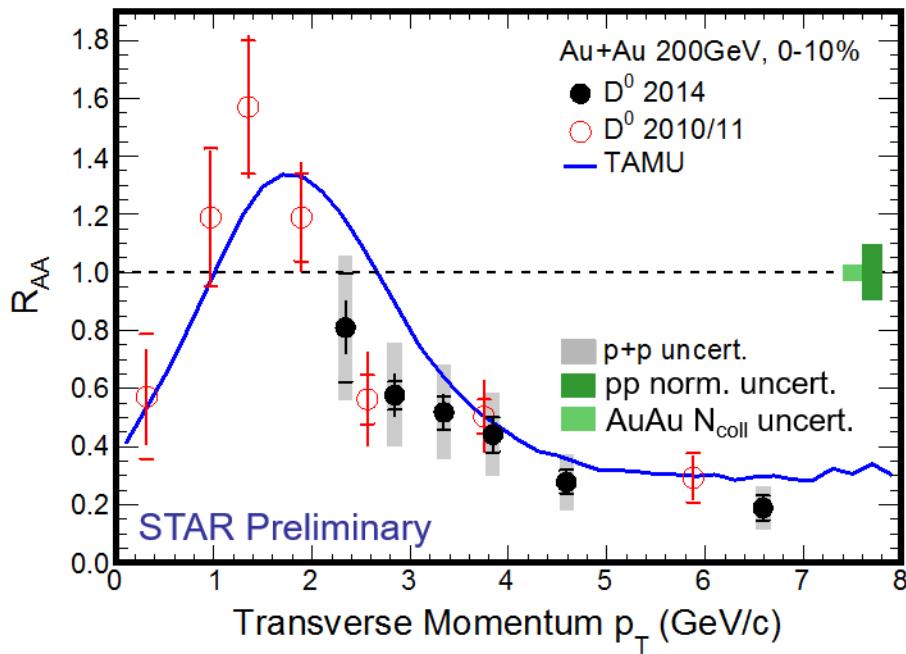
Near-Term: STAR HFT Physics Goals



Centrality dependence of charm hadron v_2
 First Λ_c measurement in HI collisions
 - coalescence hadronization
 $B \rightarrow J/\psi$ with displaced vertex at RHIC
 - bottom quark energy loss



Does Charm Flow?

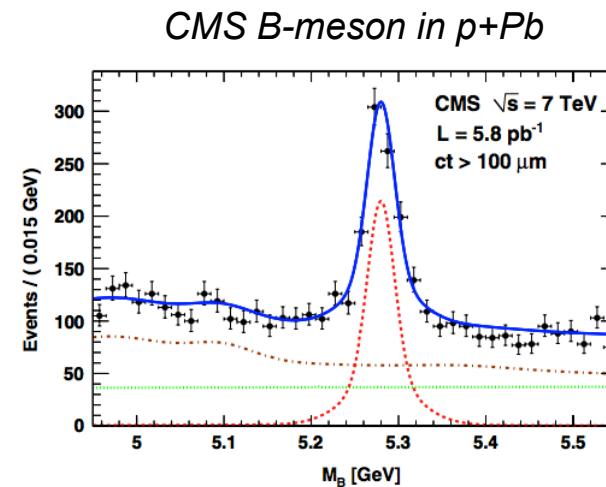
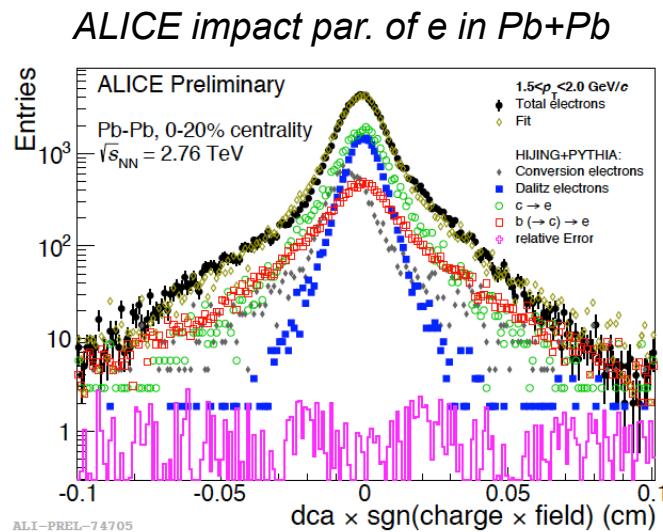
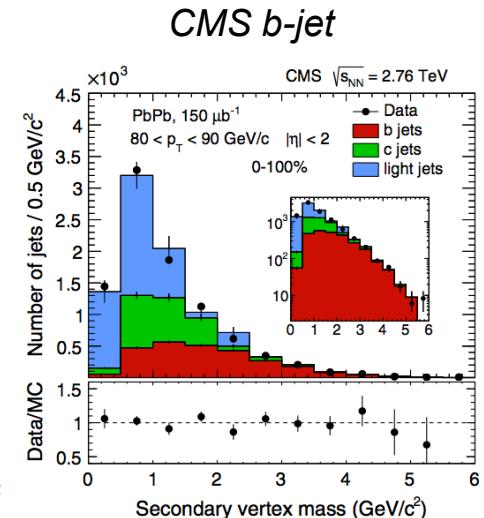
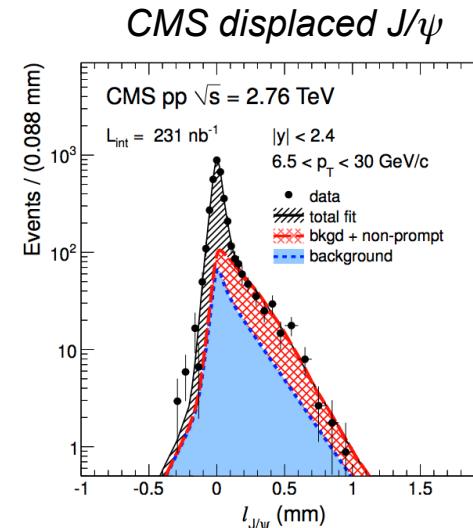
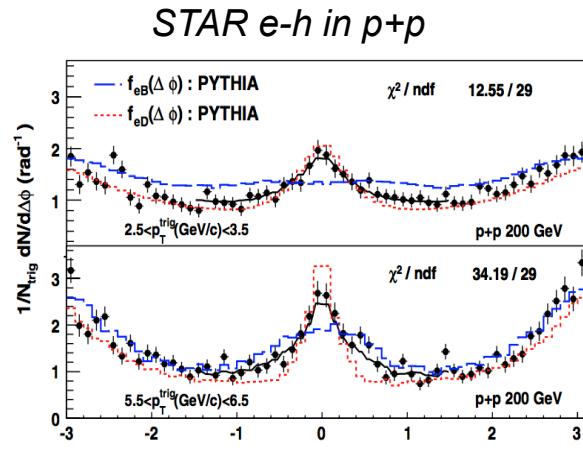


TAMU model: non-perturbative transport + Langevin simulation

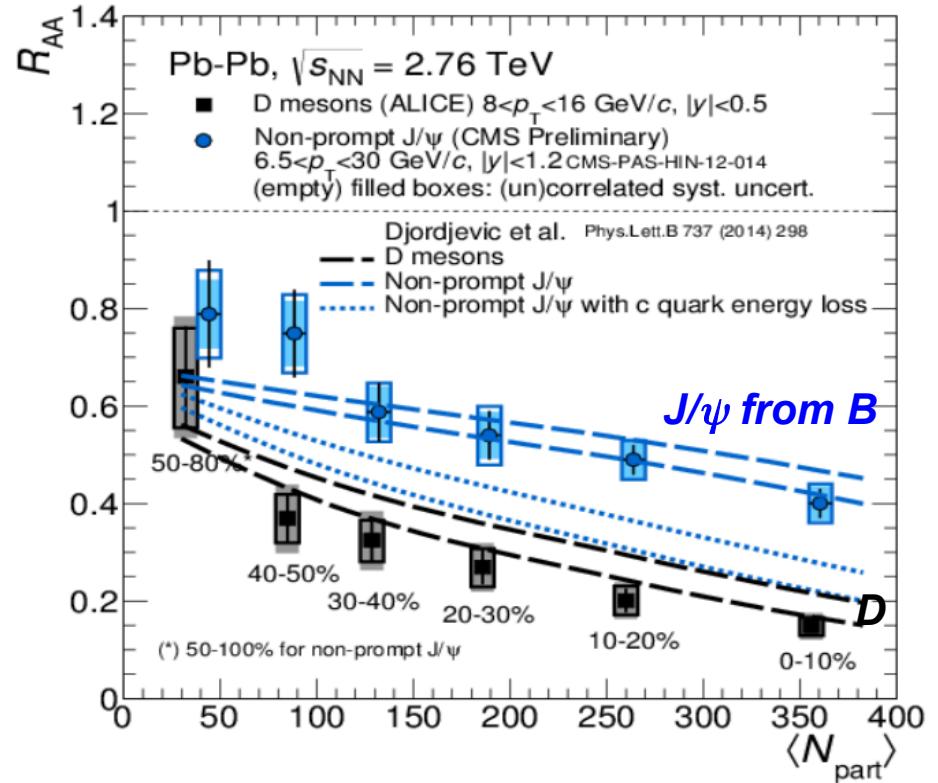
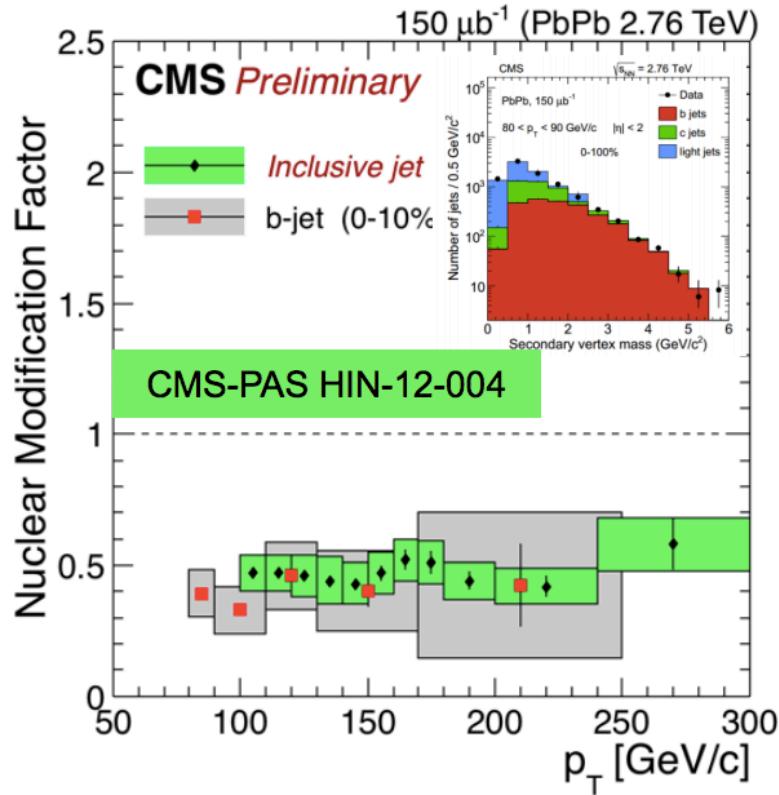
- "bump" structure in R_{AA} at low->intermediate p_T
 - coalescence of flowing charm + light quarks
- D-meson v_2 data favor charm quark diffusion / flow in the medium

Measuring Bottom

Lower production rate! Lower branching ratios for exclusive reconstruction!



Bottom Suppression in Heavy Ion Collisions



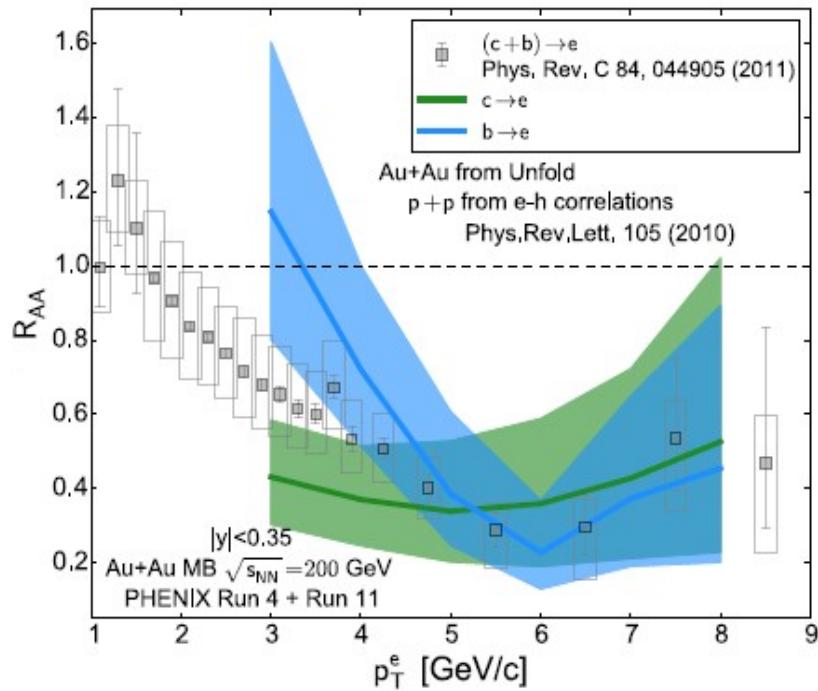
ALICE JHEP 09 (2012) 112, CMS-PAS-HIN-12-014, ALICE arXiv: 1506.06604

R_{AA} of b-jets at $p_T > 80 \text{ GeV}/c$ comparable to that of light jets
caveat: sizable gluon splitting contribution

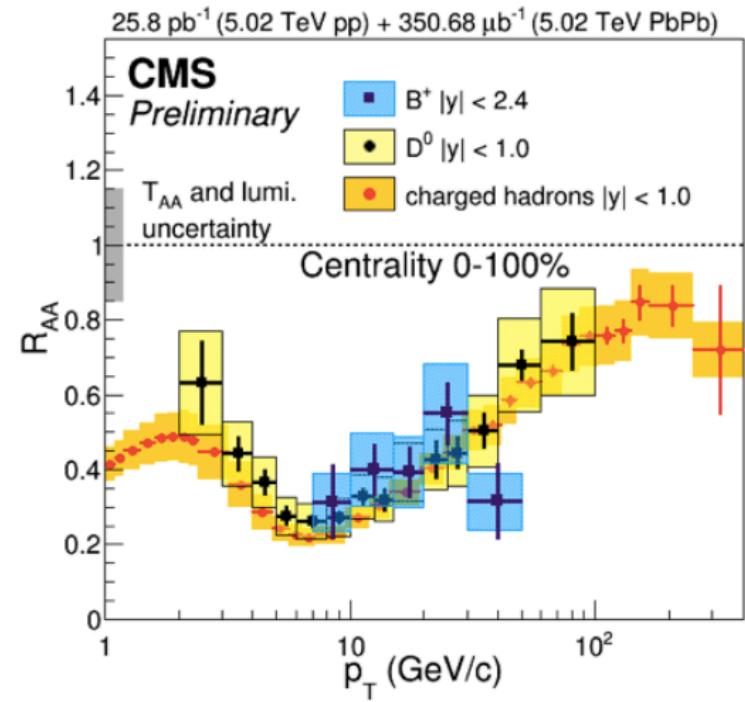
Suppression hierarchy between $R_{AA}(J/\psi^B)$ and $R_{AA}(D)$ at LHC
– consistent with pQCD calculations

Current Bottom Measurements

RHIC

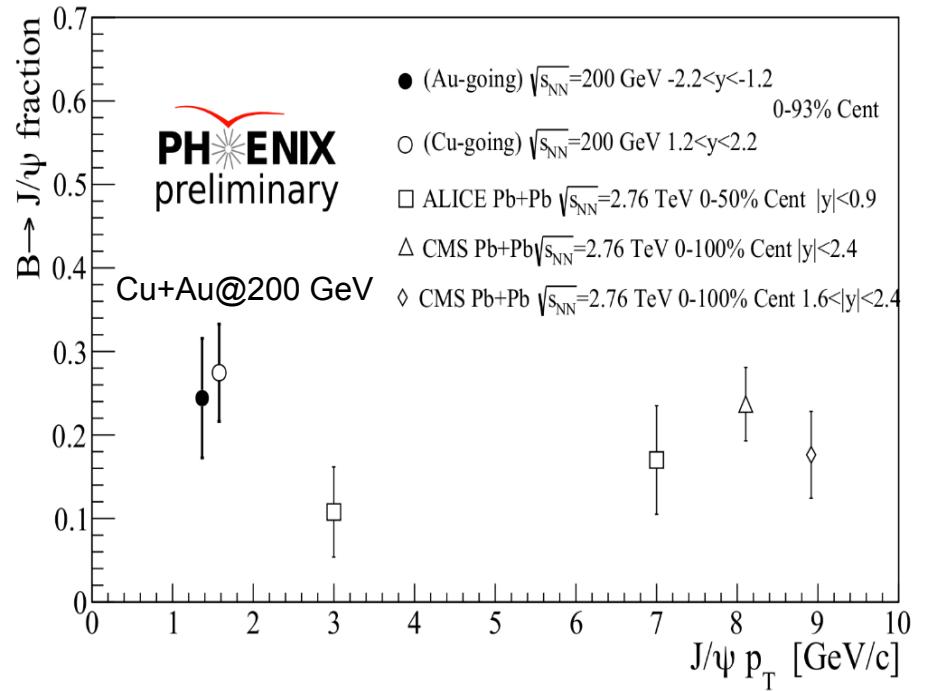
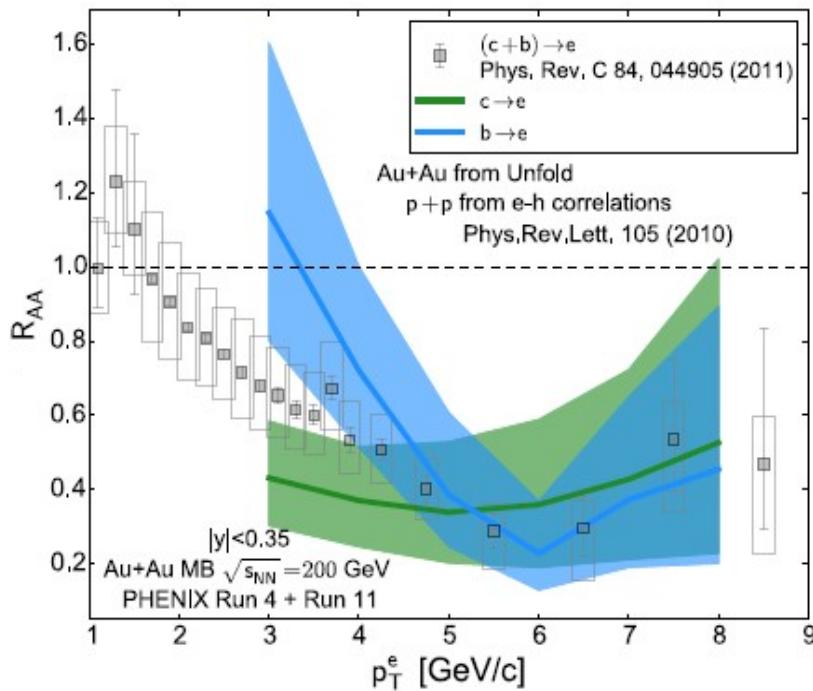


LHC



Measuring Bottom at RHIC

Separation of c and b contribution to electrons / non-prompt J/ ψ
using impact parameter method with VTX and FVTX at PHENIX



PHENIX, PRC 93 (2006) 034904

Statistics are challenging, hint of less suppression for bottom quark

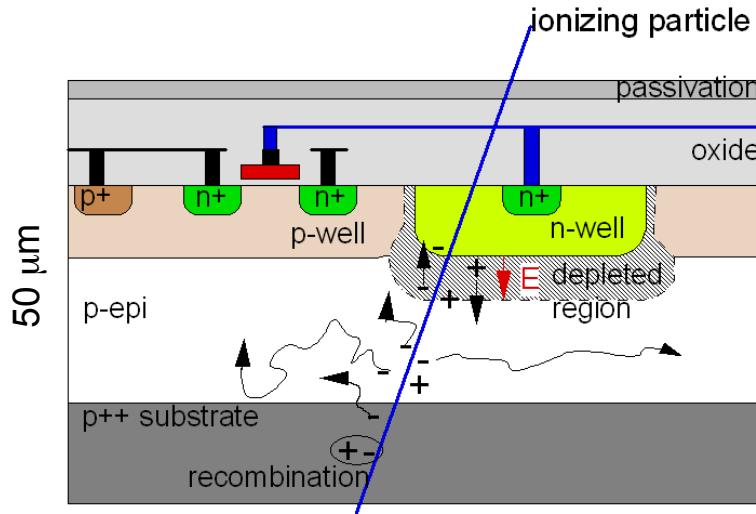
→ High statistics measurement in future heavy flavor program at RHIC

Key Instruments – Pixel Silicon Detector

	ATLAS	CMS	ALICE	PHENIX	STAR
Sensor tech.	Hybrid	Hybrid	Hybrid	Hybrid	MAPS
Pitch size (μm^2)	50x400	100x150	50x425	50x425	20x20
Radius of first layer (cm)	5.1	4.4	3.9	2.5	2.8
Thickness of first layer	$\sim 1\% X_0$	$\sim 1\% X_0$	$1\% X_0$	$1\% X_0$	$0.4\% X_0$

Monolithic Active Pixel Sensors (MAPS)

MAPS pixel cross-section (not to scale)



Properties:

- Standard commercial CMOS technology
- Sensor and signal processing are integrated in the same silicon wafer
- Signal is created in the low-doped epitaxial layer (typically $\sim 10\text{-}15 \mu\text{m}$) → MIP signal is limited to <1000 electrons
- Charge collection is mainly through thermal diffusion ($\sim 100 \text{ ns}$), reflective boundaries at p-well and substrate

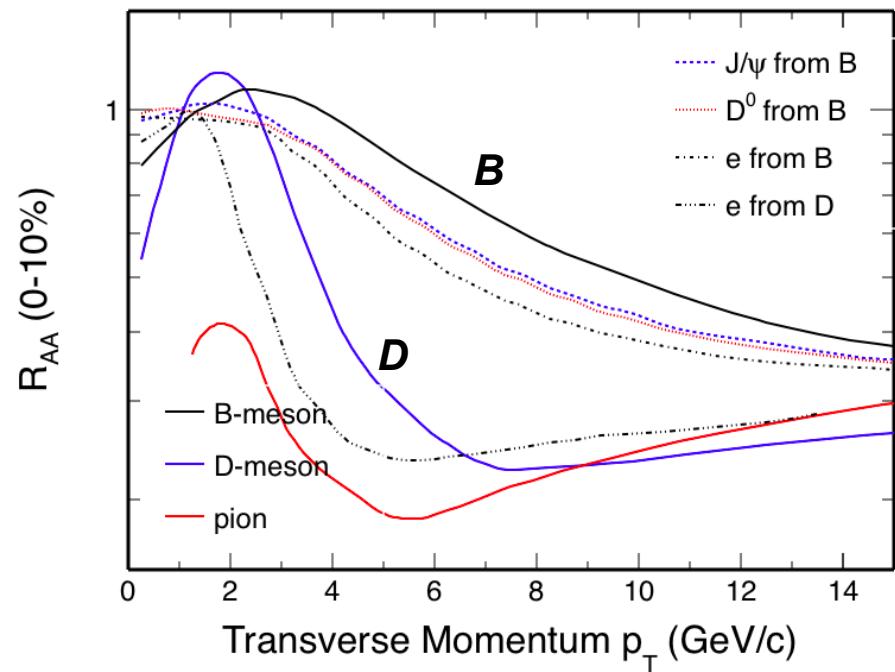
MAPS and competition	MAPS	Hybrid Pixel	CCD
Granularity	+	-	+
Small material budget	+	-	+
Readout speed	+	++	-
Radiation tolerance	+	++	-

MAPS - particularly chosen for measuring HF hadron decays in heavy ion collisions

Physics Channels

Hadron	Abundance	$c\tau$ (μm)
D^0	56%	123
D^+	24%	312
D_s	10%	150
Λ_c	10%	60
B^+	40%	491
B^0	40%	455
B_s	10%	453
Λ_b	10%	435

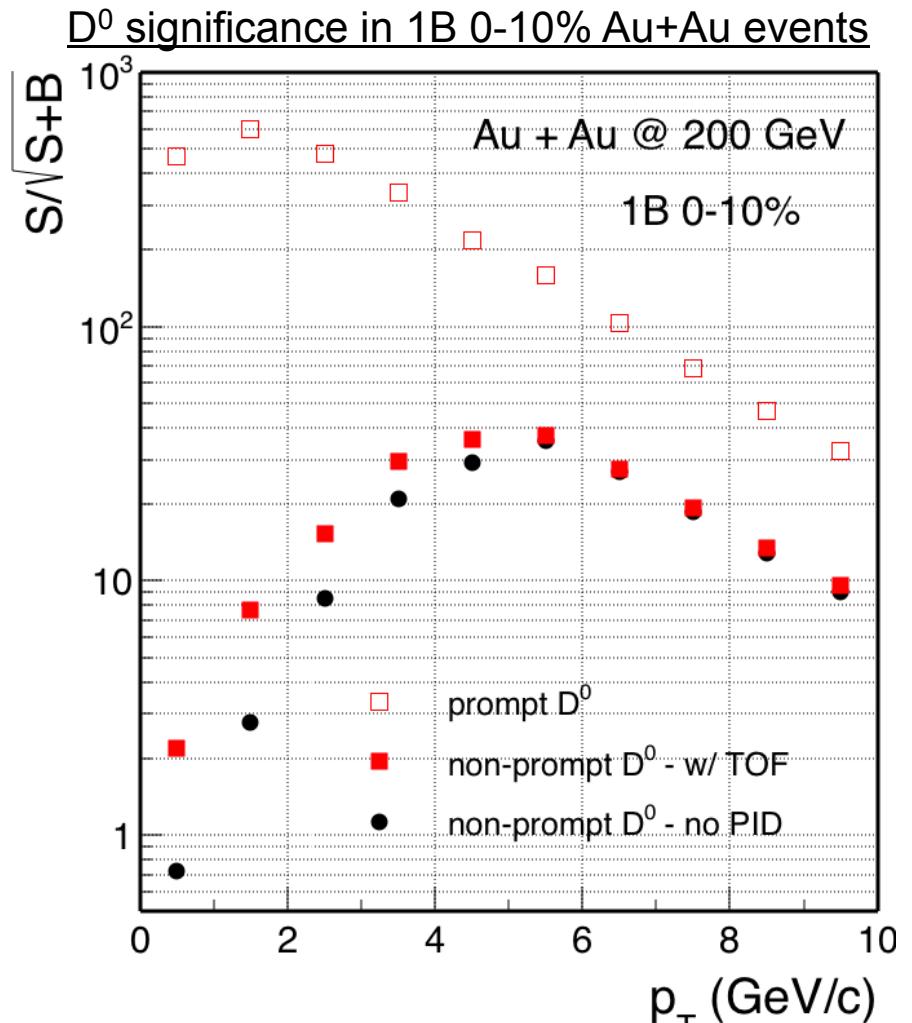
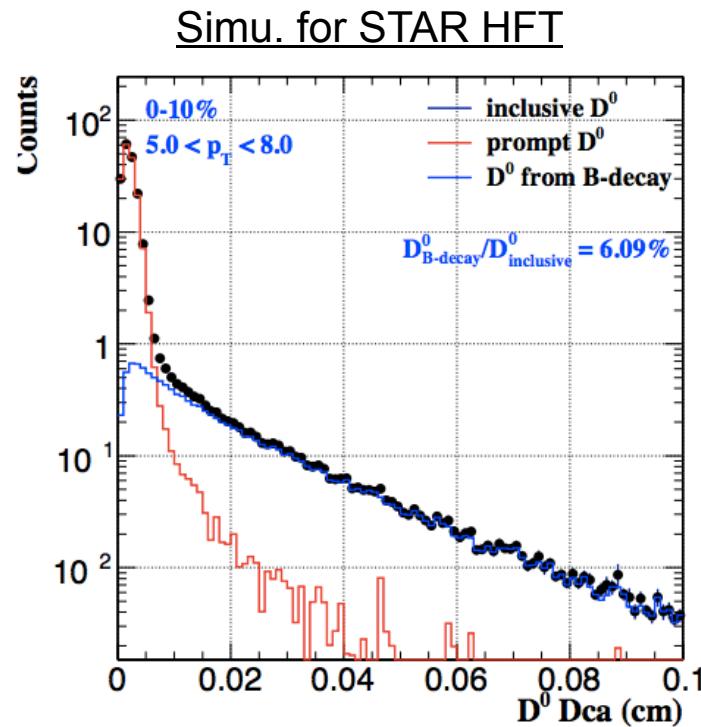
$B \rightarrow J/\psi + X$ 1.2%
 $B \rightarrow \bar{D}^0 + X$ 60% } Needed for $p_T < 10 \text{ GeV}$
 $B \rightarrow e + X$ 11% }
 $B^+ \rightarrow \bar{D}^0 \pi^+$ 0.5% }
b-tagged jet



Theory curves on B/D-mesons from TAMU/DUKE/CUJET

Estimation for Non-prompt D⁰ Measurements

Full signal and background simulation based on data-driven simulation package
- validated with full GEANT simulation for the TPC+HFT tracking at STAR



D^0 cross section - STAR measurement
Bottom cross section – FONLL* N_{bin}